Int. J. Computer Integrated Manufacturing, Vol. 84, No. 4, June 2005, 260 – 278

A CIMOSA presentation of an integrated product design review framework

KWAI-SANG CHIN,*† J. LAM,† J. S. F. CHAN,‡ K. K. POON† and JIANBO YANG§

†Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, China
‡School of Science and Technology, The Open University of Hong Kong, Homantin, Kowloon, Hong Kong, China
§Manchester School of Management, University of Manchester Institute of Science and Technology (UMIST), Manchester, UK

Integrating subsystems of manufacturing processes, material flow, organization and information to form a manufacturing system is vital to a smooth and responsive operation in the dynamic market. This article presents an integrated system framework for product design optimization in terms of cost, quality and reliability considerations, which are mapped onto the computer integrated manufacture – open system architecture (CIMOSA). The authors employ quality function deployment (QFD), value engineering (VE) and failure modes and effects analysis (FMEA) as part of a structured and targeted campaign to achieve quality, cost and reliability deployment objectives. The outcome facilitates the product design and development team to consider tradeoffs among the conflicts from customer attributes as well as the inherent fuzziness in the system.

Keywords: Product design and development; CIMOSA; IDEF; Quality Function Deployment; Value engineering; Failure modes and effects analysis

1. Introduction

Today's manufacturing sector is much more fiercely competitive and global than ever before. Some organizations have attempted to build competitive advantage by focusing on efficiency and productivity, but these efforts usually lead to only modest improvements and are easily copied (Skinner 1995). Some organizations have invested in advanced technologies (computer integrated manufacturing, flexible manufacturing systems and cells, and artificial intelligence, etc.) and management techniques (just-in-time, manufacturing resource planning and enterprise resource planning, etc.) that have significantly enhanced their ability to convert raw materials into goods and services. While these strategies have achieved impressive results in some cases, the organization's ability to develop new products to meet the customer's changing wants and needs has not kept in pace. For sustainable increases in market share and profitability, manufacturers are increasingly focusing on improving product development practices. These efforts allow companies to design products that better meet customer requirements and, at the same time, allow products to be manufactured economically and quickly.

To be champions in the marketplace, companies must become experts in developing low-cost but high-quality products. They need to integrate good controls of quality and cost management systems that ensure their products are successfully developed and launched. However, many organizations have experienced difficulties in accommodating all value elements in new product development process. Researchers have noted that many of the pertinent value elements required for product design and development could not be merely imposed either through identification of quality dimensions or fully addressed through a total

*Corresponding author. Email: mekschin@cityu.edu.hk

International Journal of Computer Integrated Manufacturing
ISSN 0951-192X print/ISSN 1362-3052 online
http://www.tandf.co.uk/journals
DOI: 10.1080/09511920512331317827

quality management (TQM) based process alone (Bhote 1997).

Many researchers had proposed developing an integrated product design system using concurrent engineering (Lu *et al.* 1999, Chen and Jan 2000, Herder and Weijnen 2000, Senin *et al.* 2000, Wu and O'Grady 2000). Most of the literature deals with issues such as manufacturability, assembly, cost reduction, quality deployment, product assurance, etc. (Dembeck and Gibson 1999, Ke 1999, Liu and Yang 1999, Swanstrom and Hawke 1999). Quality, cost and reliability are the three major essential elements that influence customers buying decision (Prasad 1999). Only a few articles have considered aspects of integration of quality, cost and reliability management during the design phase of the product (Kara *et al.* 1999, Minderhoud 1999). The authors have recently studied the development of an integrated design review tool in support of product development team in optimizing various issues of new product development. The design optimization occurs in an environment where various constraints associated with quality cost and reliability have impacts upon the product design. Open system architecture for computer integrated manufacturing (CIM) is employed in the development of the design review tool. The CIMOSA (CIM-open system architecture) provides open system reference architecture to systematically derive the approach of particular requirement definition, design specification and implementation description. This article will discuss an integrated product design review framework for product design optimization based on the CIMOSA architecture. It aims to facilitate product development teams to evaluate tradeoffs among various conflicts between customer attributes and manufacturing constraints as well as the inherent fuzziness, and then determine target values for the product designs.

2. CIMOSA: an open system reference architecture

CIMOSA, derived from the ESPRIT-funded consortium AMICE (a group of major European companies and research institutes), aimed to develop an all-embracing conceptual framework in implementing CIM (ESPRIT 1991). CIMOSA is a reference model and a complete description of a manufacturing enterprise using various representations such as organization, resource, information and function. It describes, using these representations, each function and its activities of the enterprise in generic form. The areas within the scope of CIMOSA are product information, manufacturing planning and control information, shop floor information and basic operation information. As an open system reference architecture for CIM, CIMOSA supports the definition, development and continuous maintenance of a consistent architecture and its related operational system for a particular enterprise. This particular architecture will provide the explicit structure of the enterprise operation and thereby allow the modelling, simulation and control in real time of all internal and external information needs of the total enterprise, including its relationships to suppliers, customers, government agencies, financial service, etc. (McDonough III *et al.* 2001, Molina and Bell 2002).

The modelling framework, as shown in figure 1, structures the CIMOSA reference architecture into generic and partial modelling, with each level supporting different views on the particular enterprise model. The concept of views allows the business users, in particular, to work with a subset of the model for their particular area of interest rather than with the complete model. CIMOSA has defined four different modelling views, namely, function, information, resource and organization. This set of views may be extended if needed. The CIMOSA reference architecture supports three modelling levels of the complete life cycle of enterprise operations: requirements definition, design specification and implementation description. Again, the sequence of modelling is optional. Modelling may start at any phases of the life cycle and may be iterative as well. Application integration is supported by the CIMOSA integrating infrastructure, which provides a set of generic services to support enterprise engineering and operation in heterogeneous manufacturing and information technology environments according to the overall CIMOSA concept. Business integration itself is supported by the enterprise modeling concepts of CIMOSA and its system life-cycle concepts.

3. Research methodology

Development of an integrated design system can be defined as a set of procedures that analyses and segregates a

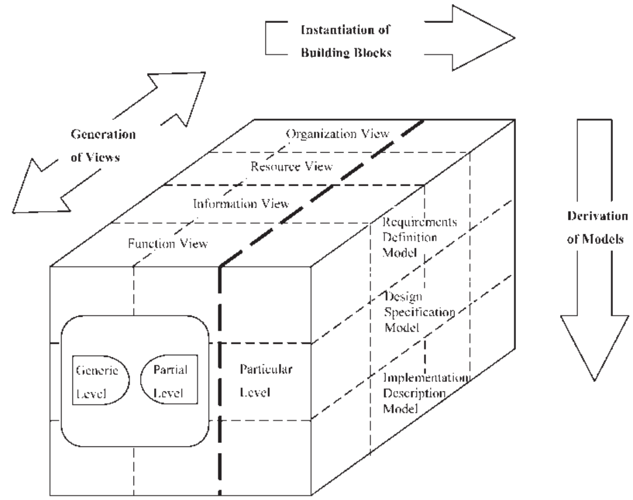


Figure 1. The CIMOSA modelling framework.

complex system design task into simpler manageable sub-design tasks while maintaining their links and interdependencies. The process of segregation, analysis and generation of solutions should lead to the development of a design methodology. In this article, the authors will make reference to the CIMOSA as primary architecture framework and adopt its concept to establish an integrated product design review framework. The development procedures are illustrated with reference to figure 2, as follows.

(1) Determine essential processes and activities to achieve particular design requirements in the function view defined in of figure 2, with reference to the well-known productivity tools – quality function deployment (QFD), function analysis system technique (FAST) and failure mode and effects analysis (FMEA). Outcome of this step is the particular design specification model in the function view, which presented by IDEF (Integrated DEFinition Method), IDEF0 Diagram (Winosky 1987, Coloquhoun *et al.* 1989, Hargove 1995, Lin and Chow 2001, Dorador and Young 2002).
(2) Determine information flows and data stores among activities defined in the particular design specification model in the function view of (2). The outcome is the particular design specification model in information view and presented by data flow diagram (DFD), (3).
(3) Establish the particular implementation description model in the function view, a framework of design review checklist is constructed according to process/activities previously defined in the particular design specification model in the function view (4).

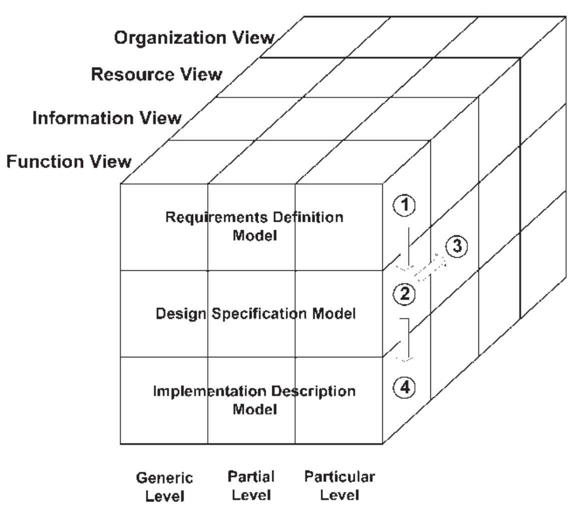


Figure 2. Sequential procedures of an integrated design review tool.

4. Particular requirement definition model (PRDM) in the function view

The PRDM provides a description of the enterprise system requirements in terms of the enterprise objectives. Identification of requirements for integrated system design starts with an analysis phase, which includes the examination of the various factors that determine the needs of the management system. It involves the acquisition of all the relevant information to define the requirements and the types of systems to be designed. In the function view, the structure, contents, behaviour, control and the functionality of the entire enterprise or domain are described. It also specifies *what are* required, namely the required structure, content, behaviour, control and capabilities in the RDM (requirement definition model), then *how* these requirements need to be implemented.

The major goals of integrated product and process design and development team is to convert a product concept into a manufacturable, saleable and profitable product in such a way that the design of the product and corresponding processes result in the following aspects (Edward 1997):

- High customer satisfaction.
- Minimum product cost with improved profitability.
- Equal or surpassed competitive benchmarks.
- Short time-to-market.
- Low product development cost.
- High level of quality and reliability.
- Least redesigns and engineering changes.

In order to optimize the product design, the authors propose an integrated product design review framework for product design and development teams to systematically evaluate the conceptual/detail design in conjunction with an appropriate analysis tool which includes quality, cost and reliability deployment techniques. The framework is proposed to be implemented preliminarily by design review checklist. Having reviewed literatures for function, cost and reliability deployment processes, the authors summarized their respective overall objectives in table 1. These objectives are defined as the integrated system requirements (Whats).

After identifying the 'Whats', which are needed in the integrated system, the users should consider how these requirements are to be implemented. It is suggested that modern quality tools and techniques are employed to realize the system objectives. Experience has shown that quality tools can yield significant results in assisting the quality improvement process (Tummala and Kwok 2001). The quality tools provide a succinct method for graphical and tabular display of data in a summarized yet informative format. The displays are excellent aids for understanding the vital factors that determine product characteristics and thus guide the designer towards the proper course of action. The quality tools in particular tend to be singled out for their value. The authors have employed quality function deployment (QFD), value engineering (VE) and failure modes and effects analysis (FMEA) as part of a structured and targeted campaign to achieve quality, cost and reliability deployment objectives. In table 2, it is clearly described how the selected quality tools contribute to implementation of 'Whats'.

5. Particular design specification model (PDSM) in function view

Particular design specification model (PDSM) is to decouple the PRDM from the implementation description modelling level to reduce the impacts of changes from one level to another. It forms a stable base between the requirement definition and the description of the final system implementation. The modelling is carried out by system designers who optimize the different system requirements from a global enterprise standpoint. The DSM (design specification model) in the function view is created by IDEF0 methodology (Chen *et al*. 1997, Bahill *et al*. 1998, Lin and Chow 2001), which act as a road map for the stepwise introduction of new systems into the new product design environment. In essence, the DSM shows us an idealized design procedure, which takes cognizance of the ideas for change and design principles presented earlier. The DSM fulfils the particular functional requirements, as well as presents a systematic approach to development and implementation of the quality, cost and reliability deployment objectives. Figure 3 presents the A0 level activity of the process that outlines the general inputs/outputs, controls, and resources for the product design and development task. Figure 3 outlines the general IDEF model of the integrated system of new product development. To achieve the objectives, the DSM further maps 26 specific

Table 1. Objectives of quality, cost and reliability deployments.

	Objectives
Quality deployment	To identify and prioritize customer's needs. To design product or service to meet the needs. To determine engineering characteristics contribute to best satisfy these needs.
Cost deployment	To reduce cost while maintaining balance with quality.
Reliability deployment	To identify potential problems which would adversely affect product quality or process performance.

Table 2. Relationships between 'Whats' and QFD, VE and FMEA.

By	Whats	Hows
Quality function deployment (QFD)	Identify and prioritise customer needs.	Organize customer requirements. Establish customer importance ratings.
	Determine the product characteristics to meet customer needs.	Establish engineering characteristics.
	Design target values to best satisfy customer needs.	Determine conflicts among engineering characteristics. Determine relationship among engineering characteristics. Determine technical targets and ratings.
	Position the product in relation to competition.	Establish customer competitive comparisons.
Value engineering (VE)	To reduce cost while maintaining balance with quality.	Identify basic and supporting functions by components. Calculate component's cost. Determine functional cost.
Failure modes and effects analysis (FMEA)	Identify potential problems, which would adversely affect product quality or process performance.	Identify potential failure modes. Identify potential failure causes. Identify potential failure effects. Identify design/process control. Evaluate current control status. Provide corrective actions plan.

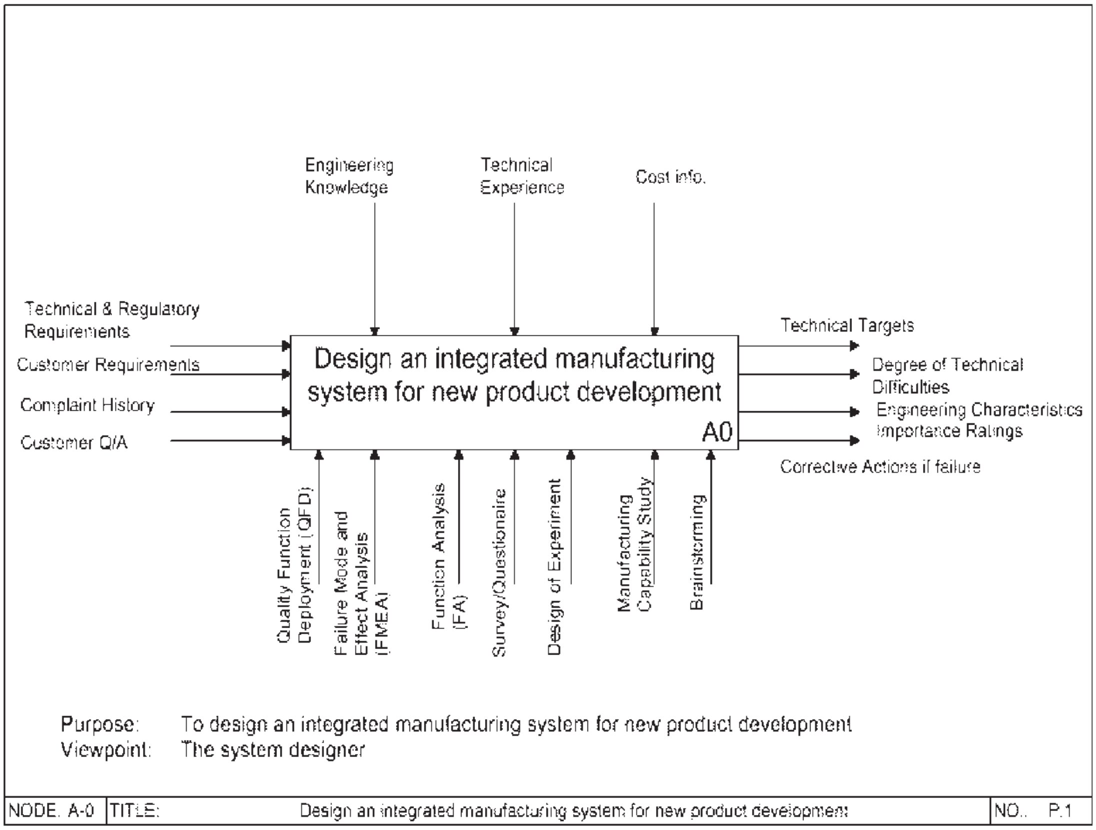


Figure 3. A-0 design an integrated manufacturing system for new product development.

activities, as tabulated in table 3, that need to be carried out with respect to the required inputs/outputs, controls and resources throughout the product design process, as depicted in figure 4. Activities A01–A05 are used to translate customer voice into engineering language, prioritize customer needs and finally establish relationship measures of engineering specifications and customer requirements. A06 is the decision making process that summarized all concerns based on product performance, customer satisfaction, product reliability and value aspects, to yield the best balanced design decision. Activities A07–A15 assesses product's potential failure causes, effects and risk level. Activity A16 mainly focuses on calculating function-to-cost ratio, to evaluate the 'worth' of the product design is. They are further elaborated as follows.

5. 1. A01: organizing the customer requirements

Referring to figure 5, customer requirements are always listed with the customers own language and may not highlight the entire customer needs. In addition to the standard technical requirements, there may be also special requirements such as government requirements, company policies or other compliances. The process of organizing these data allows the product design and development team to reach a common understanding of customer wants and also gives the team an opportunity to explore areas and requirements which the customer has not yet talked about. Customer requirements can be organized into primary, secondary and tertiary levels. While primary requirements are the basic customer wants, tertiary requirements are always described in the most detailed level. For example, in the case of a motor for car window operations, sufficient power, small in size, quiet, less current consumption are the customer wants; performance in physical, mechanical, electrical, reliability, cost are then the corresponding secondary requirements; and tertiary requirements of motor size, mounting configuration, EMI suppression, noise level, vibration level are developed accordingly.

5. 2. A02: establish customer importance rating and customer competitive comparisons

As shown in figure 6, there are two distinct areas with different objectives in the A02 activity. They can be carried out on the same customer survey. Both assessments are very important as they give the organization an under-

Table 3. Node index of specific activities of product design framework.

A0	Design an integrated manufacturing system for new product development.
A01	Organize customer requirements.
A011	Group customer requirements to primary level.
A012	Group customer requirements to secondary level.
A013	Group customer requirements to tertiary level.
A02	Establish customer importance rating and customer competitive comparisons.
A021	Establish customer importance ratings.
A022	Establish customer competitive comparisons.
A03	Establish engineering characteristics.
A04	Establish technical competitive comparisons.
A05	Establish links.
A051	Establish relationship matrix.
A052	Establish conflict matrix.
A06	Determine technical targets and ratings.
A061	Determine technical targets.
A062	Determine degree of technical difficulties.
A063	Determine engineering characteristics importance ratings.
A07	Identify failure modes.
A08	Determine root causes of failure modes.
A09	Determine failure effects.
A10	Define process control.
A11	Estimate occurrence.
A12	Estimate severity.
A13	Identify detection
A14	Calculate risk priority rating.
A15	Define corrective actions.
A16	Calculate functional cost.

standing on where its product stands in relative to its competitors in the market. The objectives of these processes are to evaluate:

(1) How important is each of the product characteristics to the customer: It will definitely be the case that the customer will assign greater importance to certain requirements than others. It is important to design review checklist to reflect these relative importance ratings.
(2) How customer rates the performance of a company on each of his /her requirements against their best competitors. It has to be examined by conducting customer surveys and competitive benchmarking studies.

Importance rating represents the relative importance of each customer requirement. It is useful for prioritizing efforts and making trade-off decisions. Assigning ratings to customer requirements is sometimes difficult, because each member of the product design team might have their own requirements. The competitive assessment is a good way to determine whether the customer requirements have been met and to identify areas should be concentrated. The assessment also contains an appraisal of where an organization stands relative to its major competitors in terms of each customer requirement.

5.3. A03: establish engineering characteristics

This process is to identify which product characteristics are required to achieve the customer requirements. Engineering characteristics must be measured in terms of measurable quantities, such as dimensional and torque measurement for physical and mechanical properties; voltage, current and dielectric strength for electrical performance; dBA measurement for noise level, etc. This translation of customer requirements into terms meaningful to a designer is a very important step and deserves considerable study and development. Brainstorming and affinity/tree diagrams can be combined with marketing knowledge to determine levels of technical details. The following factors should be taken into consideration and used when developing the engineering characteristics:

- Use the ‘if I control’ question to help determine engineering characteristics.
- Use existing data and the combined experience from team members.
- Collect all available technical data from sources such as statement of work/requests for proposal, related publications and technical interchange with the customer.
- Use brainstorming to identify any additional requirements.

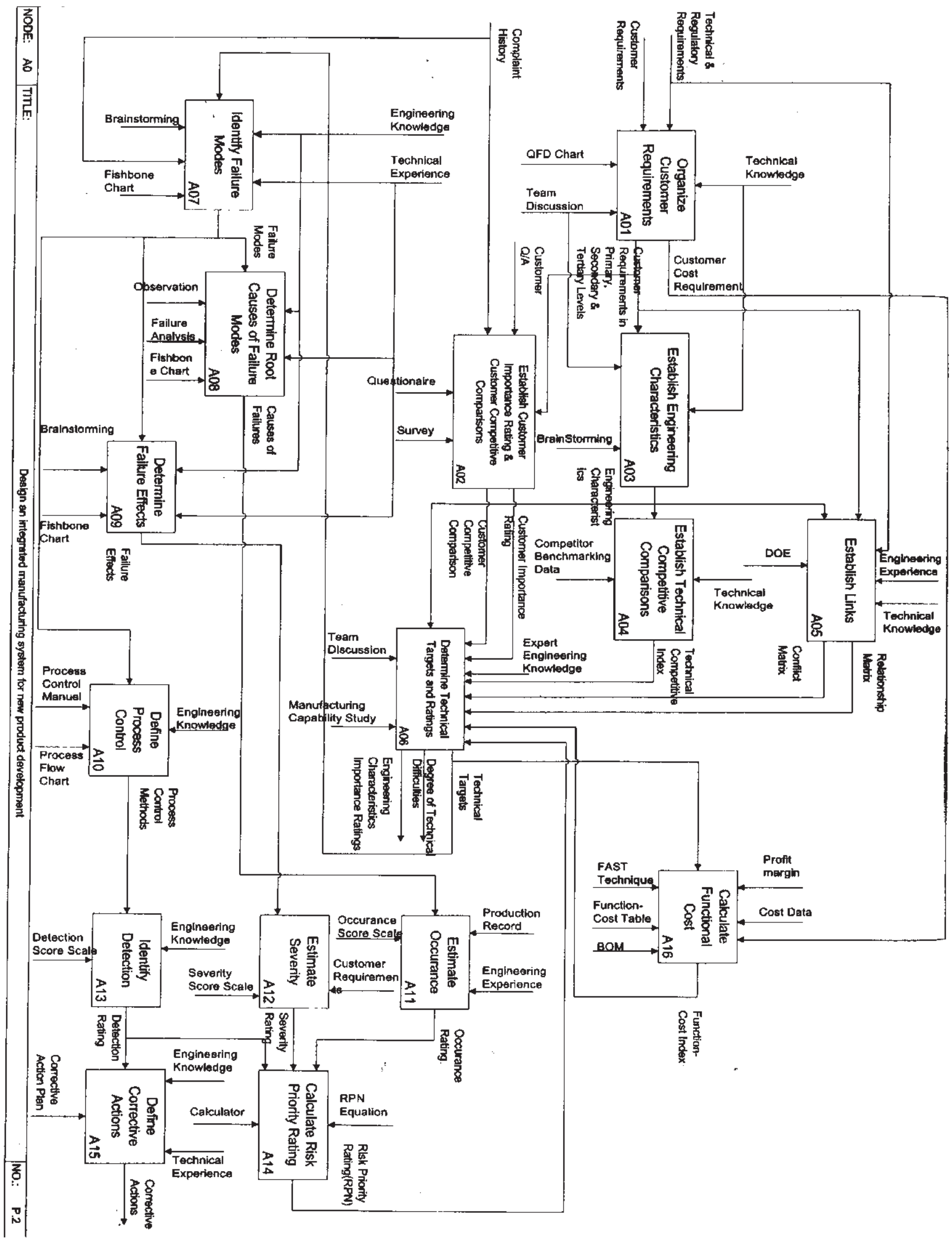


Figure 4. Overview on integrated manufacturing system for new product development.

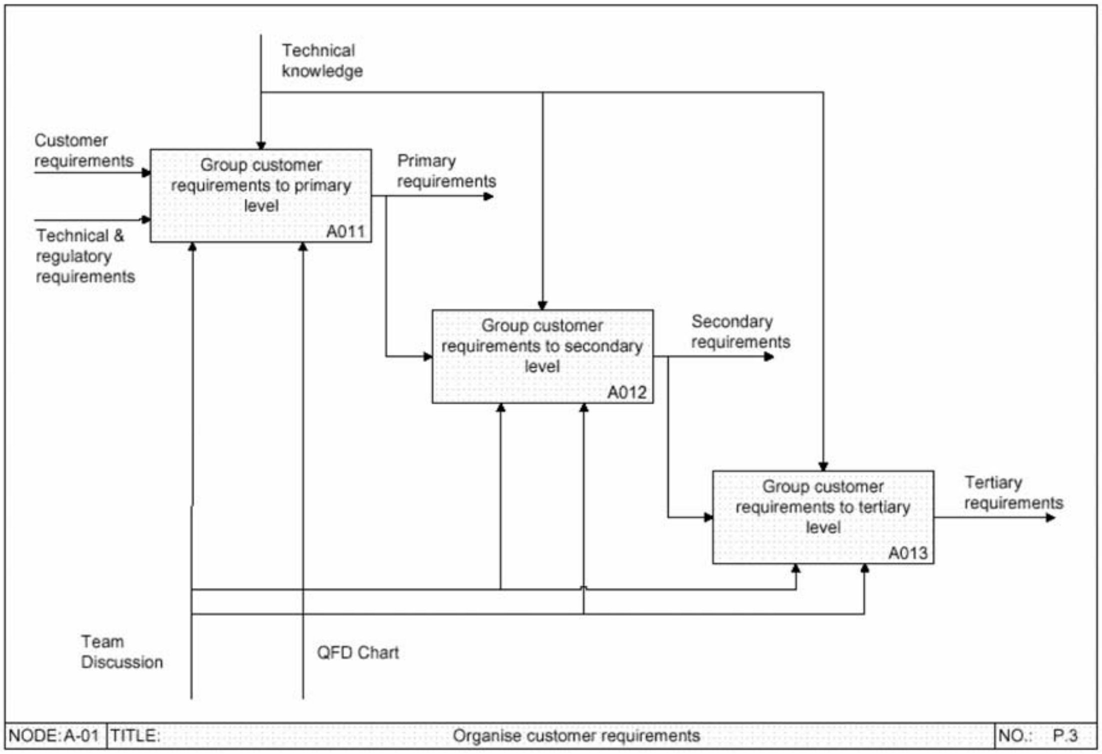


Figure 5. A-01 organize customer requirements.

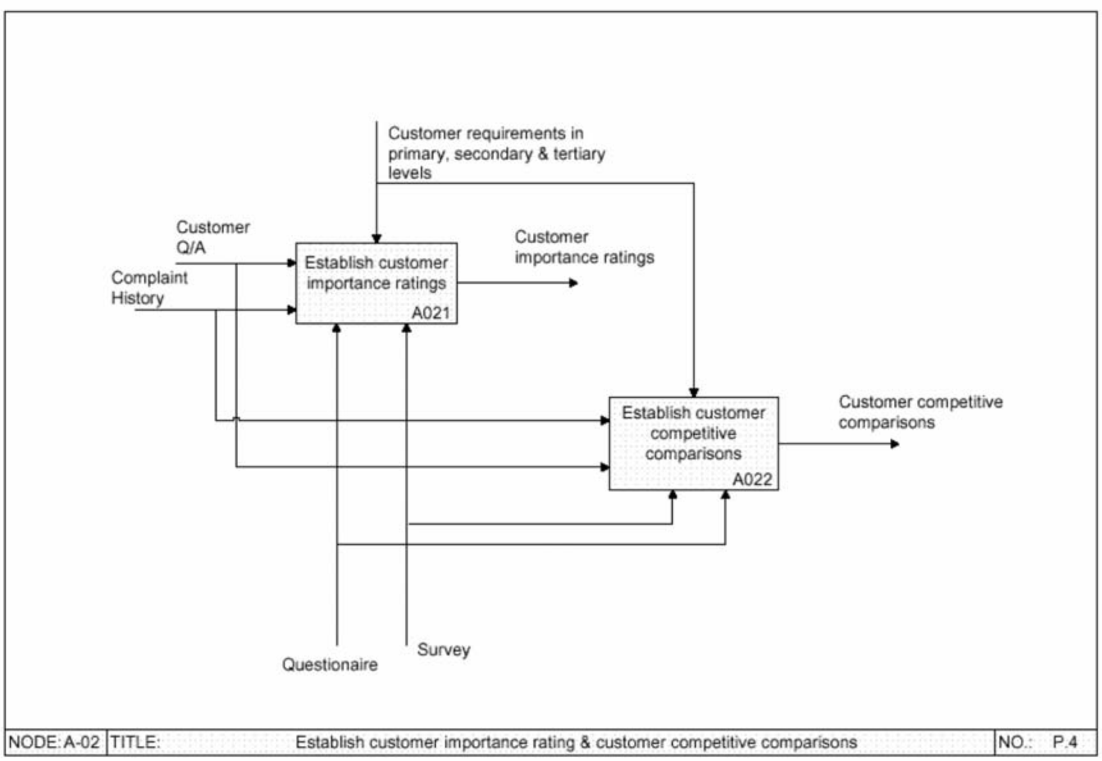


Figure 6. A-02 establish customer importance and comparison ratings.

- Use affinity/tree diagrams to organize the information.

5.4. A04: technical competitive comparisons

Competitive comparison provides a company with the hard facts about where its products stand technically in relation to its competitor products. If the company does not have an existing product, then it indicates how the buyers view the current products in the market. The technical competitive assessment is often useful in uncovering gaps in engineering judgment. When engineering characteristics directly relate to a customer requirement, a comparison is made between the customer's competitive evaluation and the objective measure ranking. The higher the value in the competitive comparison the better that requirement is perceived.

5.5. A05: establish links

Referring to figure 7, this step is to highlight the relationships between customer requirements and engineering characteristics, as well as the conflicting supporting relationships among the engineering characteristics. These relationships can be represented by a relationship matrix and a conflict matrix. The relationship matrix is a systematic means for identifying the levels of influence and effect between each engineering characteristic and the customers' requirements. A scale of 9, 3, or 1 is usually used to weight disproportionately those engineering characteristics that affect the customer requirements. This non-linear scale aids in the indication of those quantities having the highest absolute importance. This step may take a long time, because the number of evaluations is the product of the number of customer requirements and the number of engineering characteristics. Doing this in the early development process will shorten the development cycle time and lessen the need for future changes. The conflict matrix is used to highlight relationships between the engineering characteristics either positively or negatively supporting each other. Conflicts measures are extremely important because they are frequently the result of conflicting customer requirements and, consequently, represent points at which trade-offs must be made. Trade-offs that are not identified and resolved will often lead to unfulfilled requirements, engineering changes, increased costs, and poor quality. Even though it is difficult, early resolution of trade-offs is essential to shorten the product development time.

5.6. A06: determine technical targets

As shown in figure 8, after the engineering characteristics have been determined and assigned with weightings, the next step is to determine technical targets for those engineering characteristics. Technical targets are established for control purposes by the product design team in

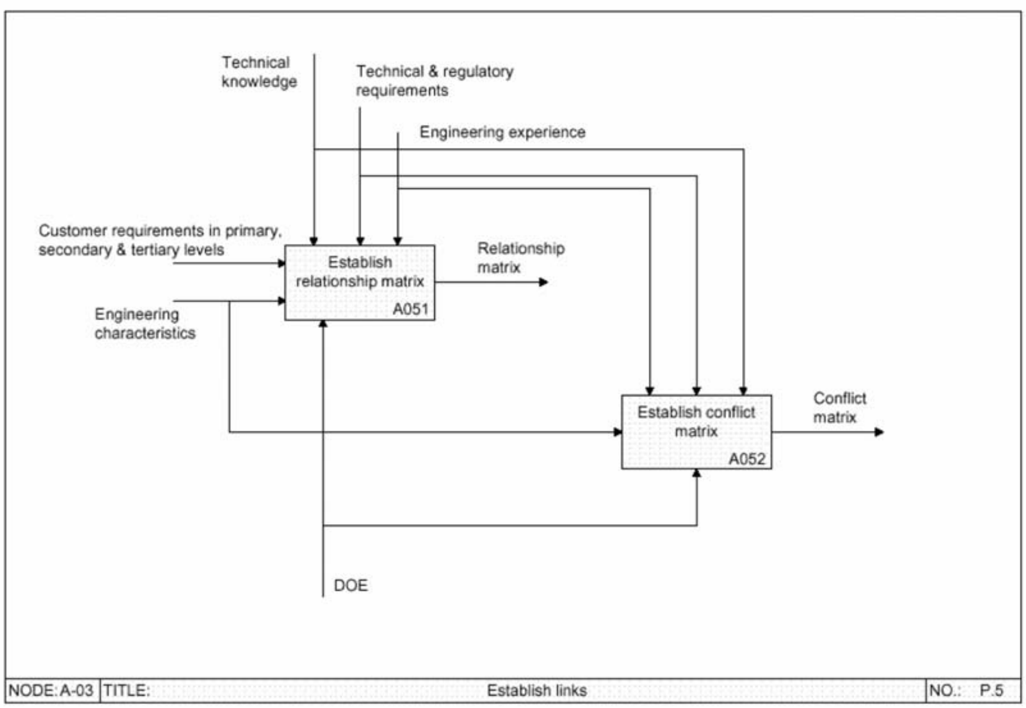


Figure 7. A-05 establish links.

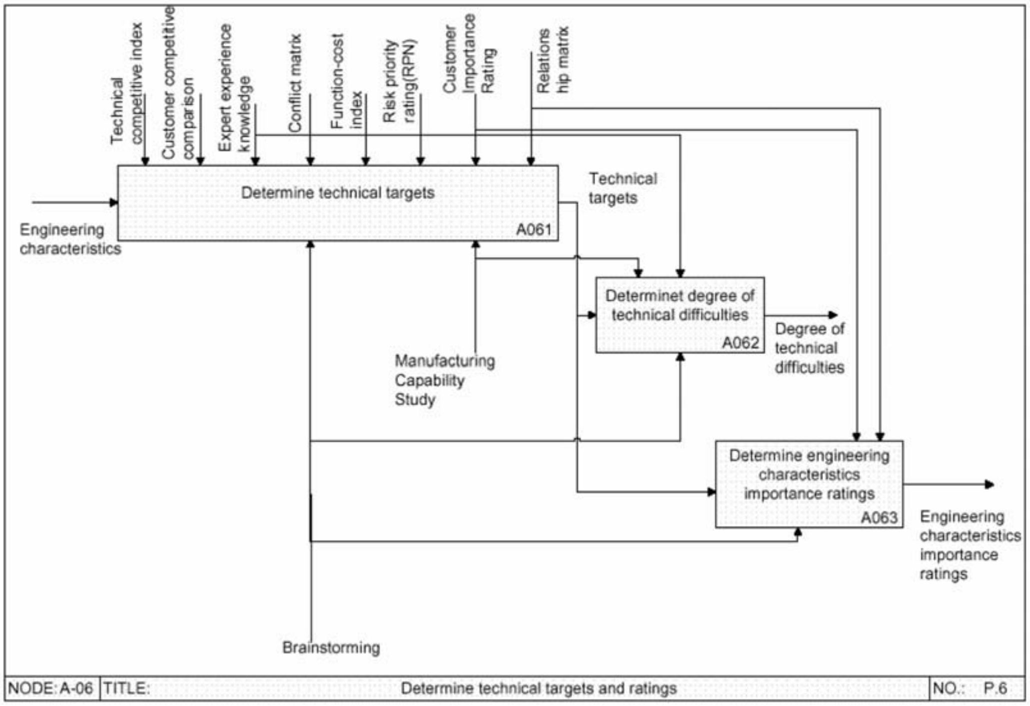


Figure 8. A-06 determine technical targets and ratings.

order to meet the customer needs. The team must be able to measure the engineering characteristics against an assigned target value. The team should firstly assign specific target values to as many of the requirements as possible. In assigning the target values, it is important to define specific goals or ranges for designers, engineers, or individuals in determining the design parameters. Design of experiment (DOE) is appropriate to be employed here to determine the validity of the target value as well as the ways to achieve the target value. Target values can be a range, or a specific target. When considering the development of target values, the design team should also consider the results of designed experiments that define optimum values, historical or operator data, statistical process control data and other benchmarking results. Finally, the product design team should keep in mind that these technical target values are often only the initial target values that should be reassessed after additional data are gathered. Target values are always revised based on tradeoffs among customer importance rating, customer competitive comparison, relationship & conflict matrix, function-cost index and risk priority rating, etc.

5.7. A07: identify potential failure modes

In order to identify the potential failure modes, the question, 'What could possibly go wrong with this equipment/part or part of the process?', has to be asked. It is important to identify all of the things that could possibly go wrong; a simple list of known warranty or other known problems is not necessarily sufficient. Some of the worst problems to afflict an organization are ones which have not occurred before. The team should not be influenced by the likelihood of the failure modes occurring, as this will be considered at a later stage. By brainstorming, all the potential failure modes should be listed. There are two major options available here. First, potential failure modes for all functions are considered in any order. Second, when particular functions are of interest for detailed analysis, the failure modes may be brainstormed for each function separately. It is worth noting that the inverse of the functions are the earliest of the failure modes to identify, but perhaps rather than focus on these, it is better to brainstorm and check that the inverse of the functions are included in the list of potential failure modes during the rationalization that follows.

5.8. A08: determine root causes of failure modes

It is essential that all the possible causes of each failure mode be identified. We must ask the question: 'What could happen to the new product concept, which could result in the potential failure mode?'. If the list of potential causes is not exhaustive, we will find that potential failures that we had intended to eradicate will recur as other causes trigger the failures. The potential causes of each failure should be identified at a brainstorming session. Failure to identify all potential causes of failure modes may result in that failure modes occur at some time in the population of products or operation of the process.

5.9. A09: determine failure effects

To determine potential effects of failure, we have to answer the question, 'What may happen if the failure mode occurs?'. For each potential failure mode, it is useful to consider and describe the effect of failure at the same level of analysis. A failure mode may have a relatively low suffering cost if the failure is found early in the product development process. Later the failure found in product development process, high the loss will result due to redesigns, rework, engineering changes and delivery delays.

5.10. A10: define process control

This stage is to define the controls that currently exist for preventing or at least detecting the failures. The process controls are intended to prevent the occurrence of failure and to detect the causes of failure or the resulting failure mode before the effect takes place. It is essential that the controls described are current and not an expectation of what may be in place at some time in the future.

5.11. A11: estimate occurrence

The occurrence rating is the numerical probability or likelihood of occurrence of a particular cause, thereby resulting in the failure mode observed. It always scores the occurrence in a scale of 1 to 10 where '1' indicates that it is unlikely to occur and '10' indicates that it is almost certain to occur.

5.12. A12: estimate severity

The severity rating is a numerical estimate of the severity of effect of the failure to the customer, where the customer may be an end user or the next operation in the process (internal customer). Again, the a scale 1–10 is always used where 1 is not significant and 10 is very serious, dangerous or catastrophic.

5.13. A13: identify detection

The detection rating is the numerical estimate of the probability of detecting a failure mode arising from a particular cause. A scale of 1 to 10 is always used in which 1 indicates that detection is highly likely and 10 almost impossible.

5.14. A14: calculate risk priority rating (RPN)

The RPN is simply the multiplication of the ratings of occurrence, severity and detection and its magnitude indicates the priority for corrective action. If the policy of mandatory consideration of corrective action is applied to severity scores of 9 and 10, the remaining causes will have rating from 1 to 800 at worst. The RPN is a quite simple guide for corrective action. In general, we should concentrate our corrective action efforts on the high scoring causes. However, there may be occasions in which corrective actions for some low scoring causes could be applied easily and inexpensively. Every opportunity should be taken to make the product or process more robust. Scarce resources should be applied to maximum effect.

5.15. A15: define corrective actions

Corrective actions have to be defined in response to the detection results. With the support of the technical experience and engineering knowledge, a corrective action plan could be developed during the product design stage.

5.16. A16: calculate functional cost index

Fundamental concept of the functional cost index can be presented by the ratio of function to cost, which identifies the worthiness of components/products. Functional cost index can be determined in two major steps: function analysis to determine component functionality; and cost analysis to determine component's level cost. Function analysis begins with an analysis of the basic and supporting functions of each component and how they are achieved. Basic functions are the principal reason for the existence of the product. The supporting functions are outcomes of the ways in which the designers choose to achieve the basic functions. Cost analysis is the procedure to identify sum of the labor, material, and burden dollars that the producer invests in the product. It includes follow-on costs during the life cycle of the product.

6. Particular design specification model (PDSM) in information view

The information system of an enterprise stores facts and information about the objects of the enterprise, their use and evolution, their links, and their constraints. The purpose of information system is to manage enterprise data and information to support the activities of the decision and physical system of enterprise. Information flowing through a company provides a multi-view representation of enterprise data, knowledge and know-how. Although it is nearly impossible to accurately model the information flow in its globality, it is fundamental to control it (McDonough III *et al.* 2001, Molina and Bell 2002).

The data flow diagram (DFD) in figure 9 represents the particular design specification model in information view, which derived from the IDEF model, figure 3, obtained in PDSM in the function view. The objective of producing the DFD is to identify information flow and necessary databases between domains within the manufacturing information system. The DFD shows the transformations that occur within systems without making assumptions about how they occur. The DFD is not a flowchart since it does not describe sequences of processes but the data flow

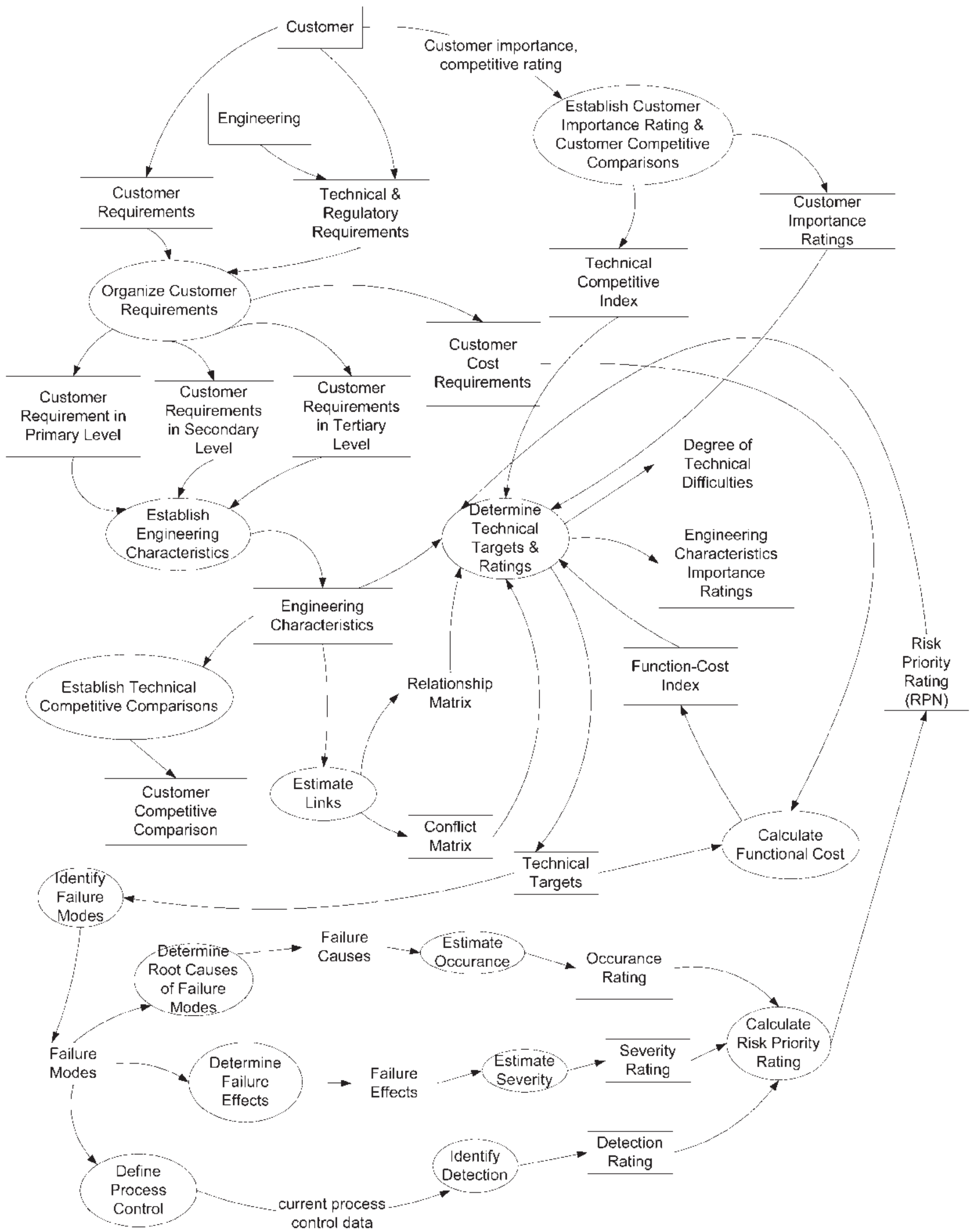


Figure 9. Data flow diagram for PDSM in information view.

of a system, without reference to time or the order of events, in a structured and graphical format. The DFD have different symbols for representing the various elements, including processes represented by ellipse, data sources/sinks represented by boxes and data stores/files represented by two parallel lines. The data inputs and outputs among system activities are summarized in the table 4.

7. Particular implementation description model (PIDM) in function view

The particular implementation description model (PIDM) is a description of functionality and behaviour of real world events, objects, process and activities of the enterprise. A design review matrix is shown in figure 10 presents the PIDM in function view, which is constructed to achieve the functional design requirements with reference to the PDSM in function view. The matrix is a multidimensional figure that shows the relationship of customer requirements to the technical targets of engineering characteristics with quality, cost and reliability deployment process. This matrix approach was originally developed by Yoki Akao, known as QFD (quality function deployment), to create linkages with value engineering and reliability charts.

The two-phase approach to implement the PDSM is accomplished by using a series of matrices that guide the product team's activities by providing standard documentation during product and process development. Figure 10 illustrates the basic two phases of the approach that structure the design review matrix into two major activities: (1) product planning; and (2) part planning. The ability to trace design and part features needs back to customer requirements is formed by taking the design characteristics from the top of the initial matrix and using them as the left-hand side of the next matrix. This waterfall process continues until specific product and part specifications result. Traceability is therefore obtained throughout the application.

Table 4. Data inputs/outputs among system activities.

Node	Process description	Data in	Data out
A01	Organize customer requirements.	customer requirements technical & regulatory requirements	requirements in primary level requirements in secondary level requirements in tertiary level cost requirements
A02	Establish customer importance ratings and competitive comparisons.	requirement importance ratings competitive rankings	technical competitive index customer importance ratings
A03	Establish engineering characteristics.	requirements in primary level requirements in secondary level requirements in tertiary level	engineering characteristics
A04	Establish technical competitive comparisons.	engineering characteristics	technical competitive comparisons
A05	Establish links.	engineering characteristics	relationship matrix conflict matrix
A06	Determine technical targets and ratings.	engineering characteristics relationship matrix conflict matrix risk priority rating (RPN) function-cost index technical competitive index customer importance ratings	degree of technical difficulties engineering characteristics importance ratings technical targets
A07	Identify failure modes.	technical targets	failure modes
A08	Determine root causes of failures.	failure modes	root causes of failures
A09	Determine failure effects.	failure modes	failure effects
A10	Define process control.	failure modes	process control
A11	Estimate occurrence.	failure causes	occurrence ratings
A12	Estimate severity.	failure effects	severity ratings
A13	Identify detection.	process control data	detection ratings
A14	Calculate risk priority rating.	occurrence rating severity rating detection rating	risk priority ratings (RPN)
A15	Define corrective functions.	detection rating engineering knowledge and experience	corrective actions
A16	Calculate functional cost.	technical targets cost requirements	function-cost index

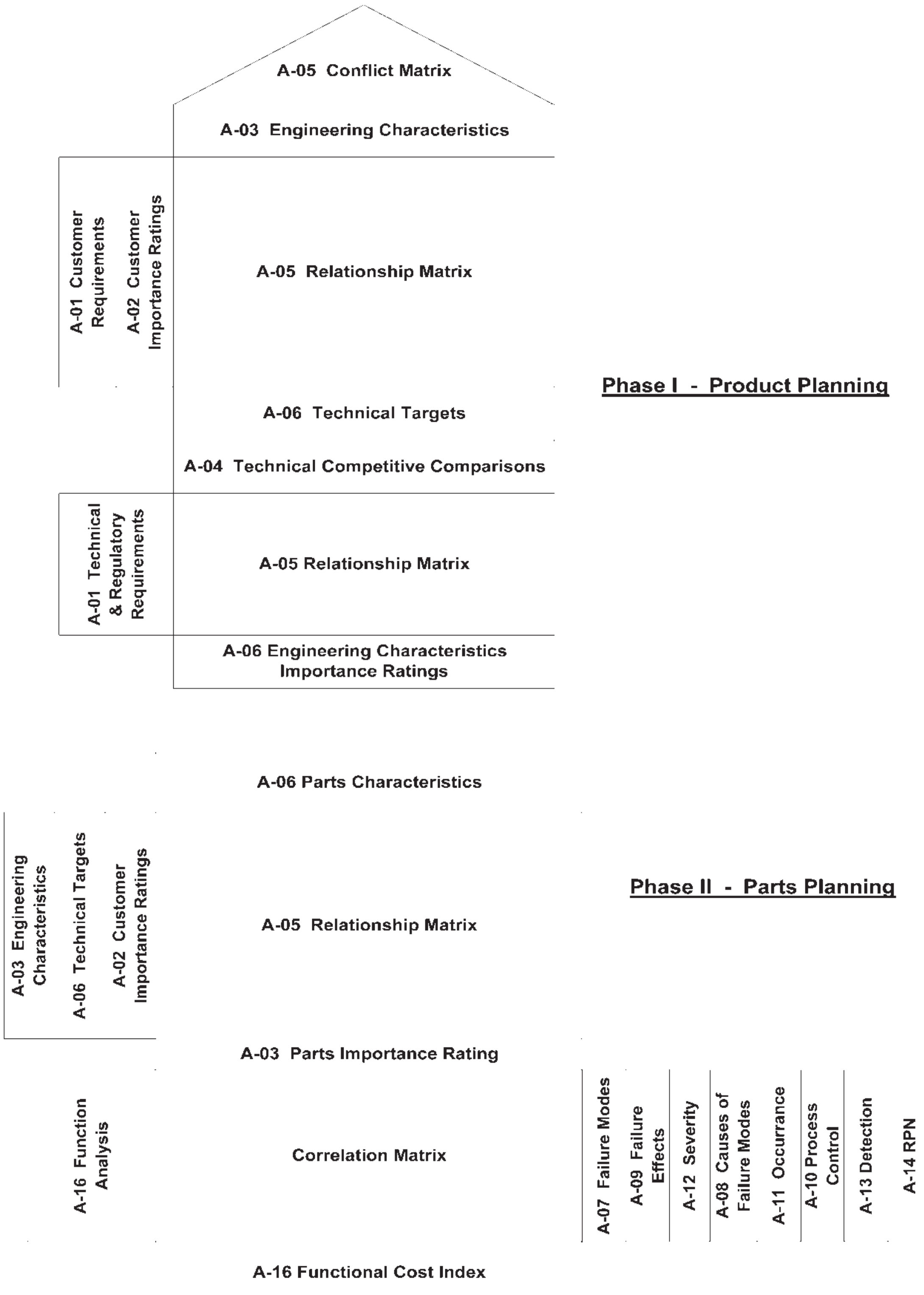


Figure 10. Implementation model – product design review Phases I and II.

Phase I of the design review matrix is used to translate the customer voice into corresponding engineering characteristics. Therefore, it provides a way of converting qualitative customer requirements, drawn from market evaluation into specific, quantitative engineering characteristics. Phase II moves one step further back in the component design and assembly process by translating the engineering characteristics into critical parts characteristics. This is accomplished by taking selected design requirements from Phase I and bringing them onto the Phase II chart as WHATs. The HOWs of design deployment are part characteristics. In addition, the Phase II chart is used to evaluate further the individual part characteristics by cost and reliability deployment.

In Phase I, the construction of the design review matrix starts with the identification of the customer requirement (A01), as listed on the left-hand side. The left-hand side describes product characteristics or represents areas of concern. Next to each customer requirement, its relative importance in numerical terms (A02), as perceived by customer is added. The right-hand side of the matrix is constructed of customer evaluations of how the product stands relative to the competition (A02). In this way, opportunities for improvement will be identified and competitive advantage is gained. This representation is also known as a perceptual map and provides a comparative assessment in relation to the products of other competitors. The product is then described in terms of its engineering characteristic (A03), which are listed along the top of the matrix. Each engineering characteristic is likely to affect one or more customer requirements. At this stage, further rows could be added below the initial customer requirement rows describing, for example, the engineer's estimates as to the degree of technical difficulty in making changes (A04). The main body of the matrix is filled in, providing a relationship matrix (A05) linking engineering characteristics to customer requirements. On top of the checklist, is the conflict matrix (A05) evaluating levels of conflicts among each engineering characteristic to the others. Objective measures are added at the foot of the checklist, which eventually is moved to form target values (A06) for a new or redesigned product. The last two rows of the engineering characteristic are the absolute and relative engineering importance ratings (A06). These ratings are a combination of the customer importance

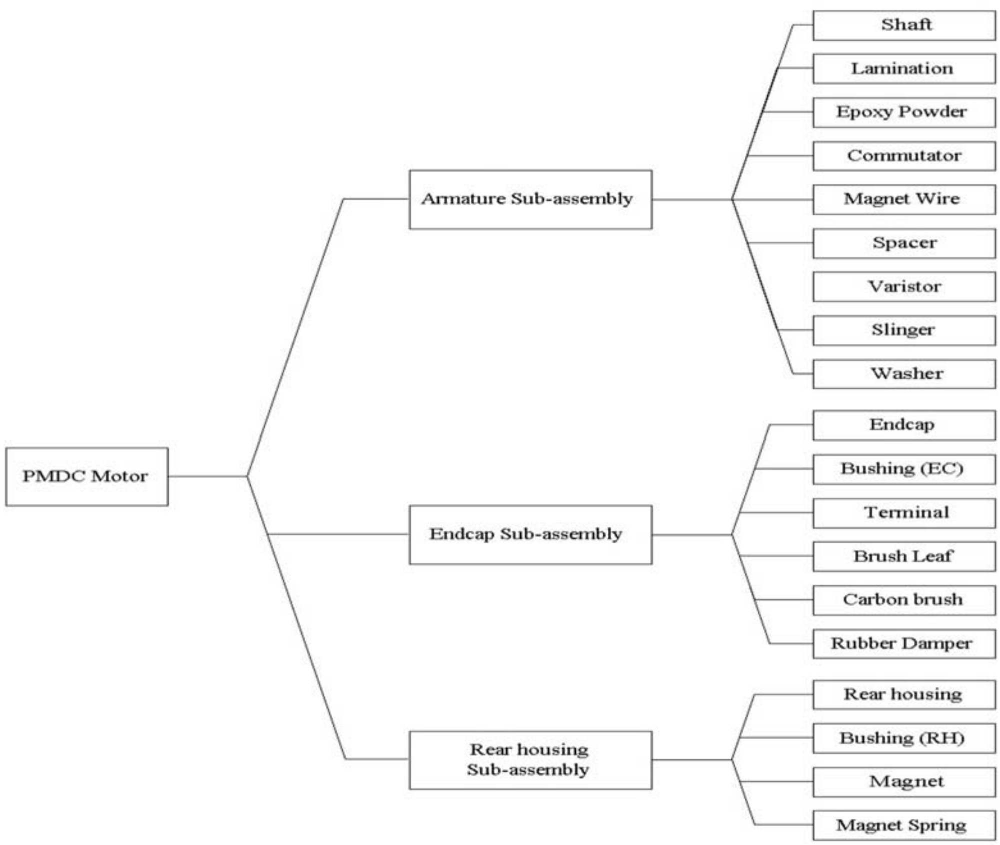


Figure 11. Hierarchical structure of PMDC motor.

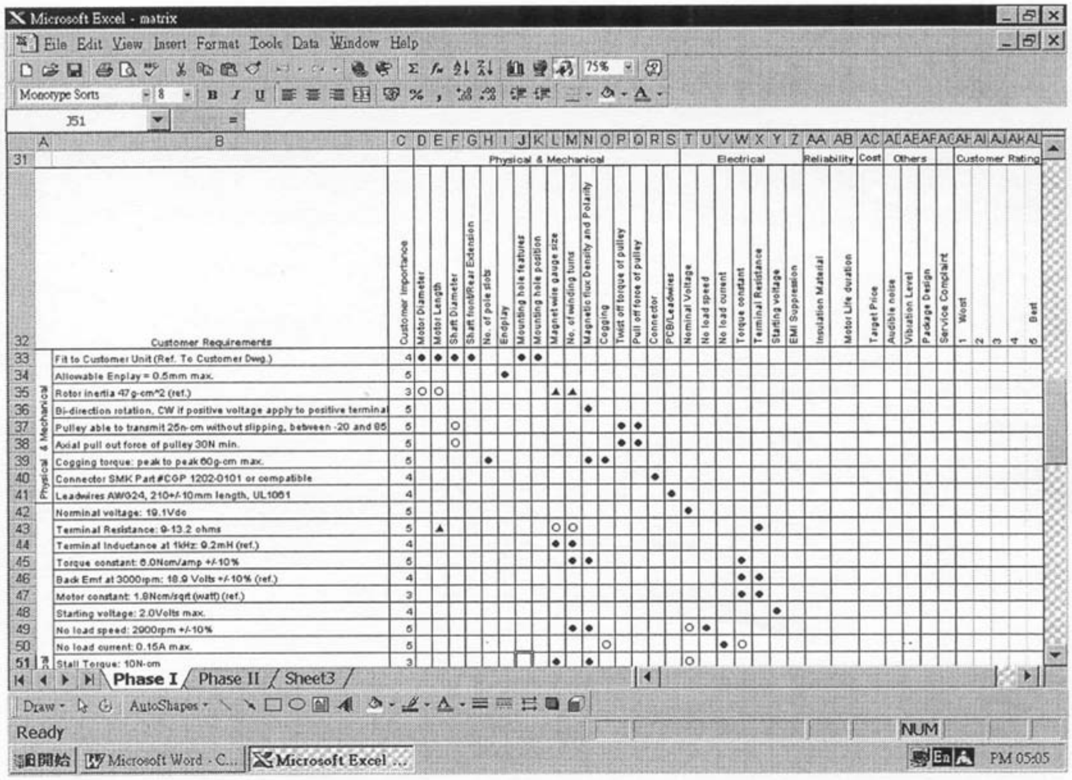


Figure 12. Assessment on customer requirements and engineering characteristics.

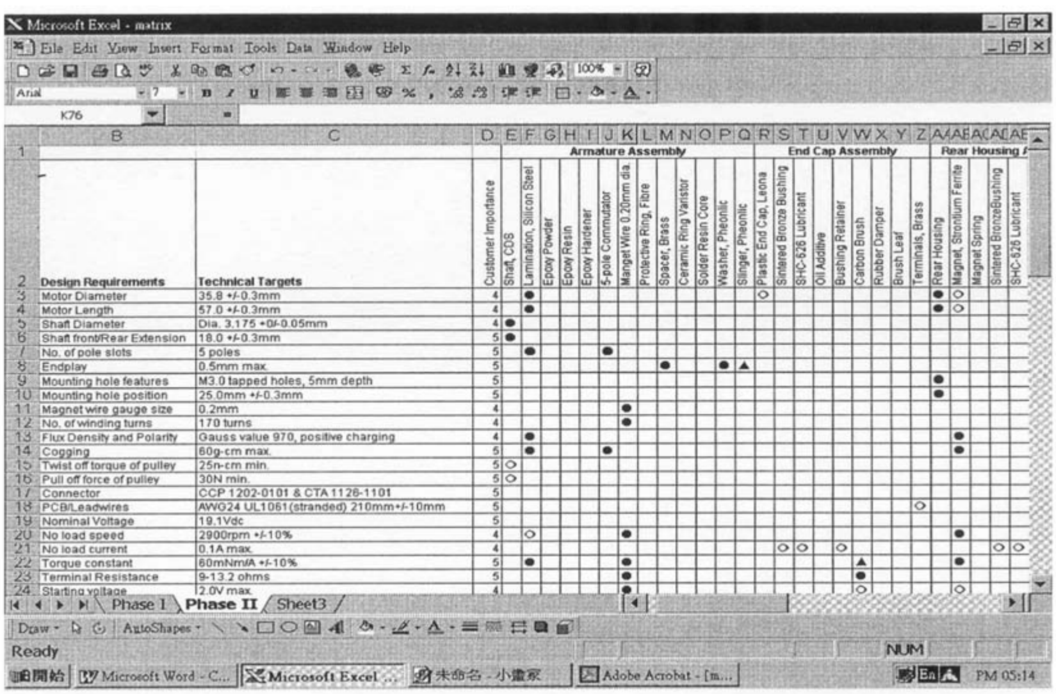


Figure 13. Assessment on design requirements and part characteristics.

rating and the strength of relationships between the customer requirements and the engineering characteristics.

In Phase II, the engineering characteristics acquired in the Phase I table (A03) are rewritten on the left-hand side of the checklist. Next to the column of engineering characteristics are technical targets (A06) and customer importance (A02) columns, which defined values that must be obtained to achieve the engineering characteristics and its importance to customer expectations. The part characteristics (A06) are then described on top of the checklist, which specify which physical parts fulfil the engineering characteristics and its target values. Similar to the Phase I table, the main body of the checklist is filled in the relationship matrix linking engineering characteristics and part characteristics (A05). Part importance ratings (A05) are a combination of the customer importance rating and the strength of relationships between the engineering characteristics and the part characteristics obtained. For each part characteristic, it is necessary to describe corresponding basic functions and supporting functions on the left-hand side of the checklist. It is a so called function analysis process (A16). The function-cost index (A16) can be determined by reviewing cost data of individual physical parts and their importance rating to customer. Extending the function description column towards the left-hand side, potential failure modes of each functions are listed (A07). Based on the identification of failure modes, one ought to brainstorm what are the effects on the customer if the failure mode occurs. All possible failure effects (A09) and their severity ratings (A12) should be recorded in the checklist. Then, it is essential that all the possible causes of each failure mode (A08) and their occurrences (A11) are identified. The current controls (A10) are those process controls that are intended to prevent the cause of failures occurring and their detectability (A13) are then listed on the next columns. Finally, risk assessment (A14) of each function is obtained by simply multiplying of the occurrence, severity and detection ratings. The reliability deployment ensures a product will perform as desired during its product life cycle.

Conclusion

This article provides an integrated model framework for the management of strategic tradeoffs in new product

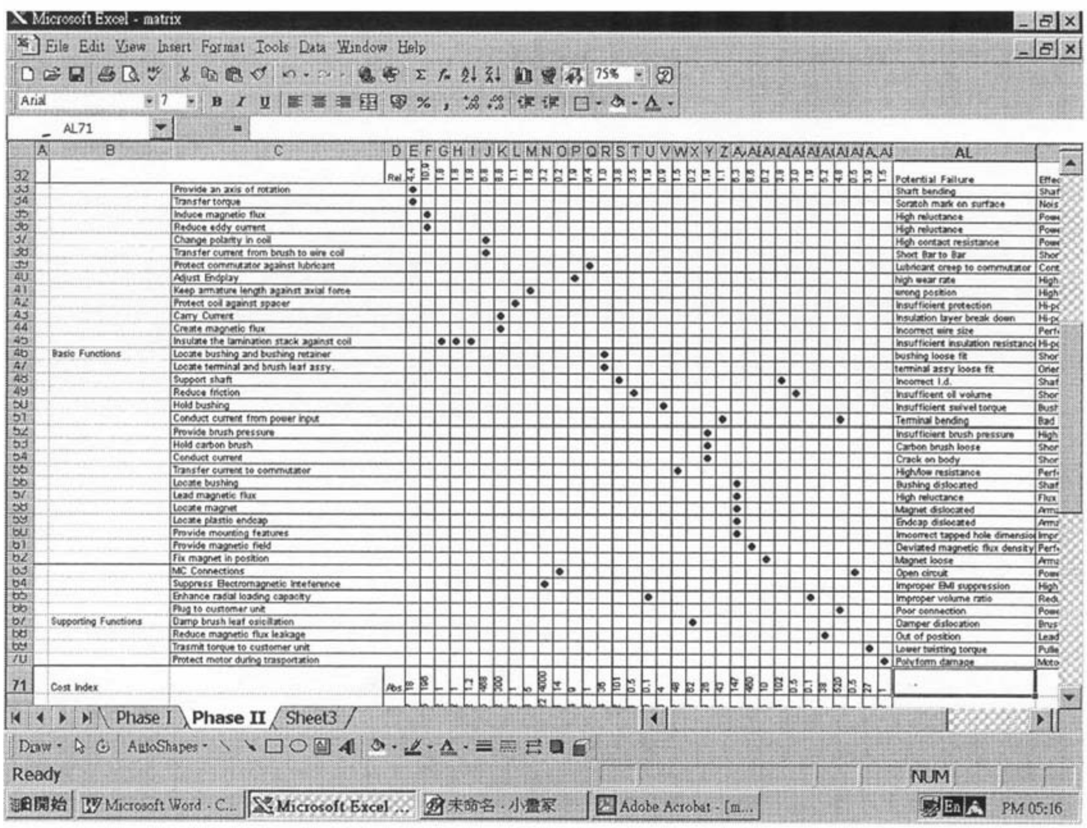
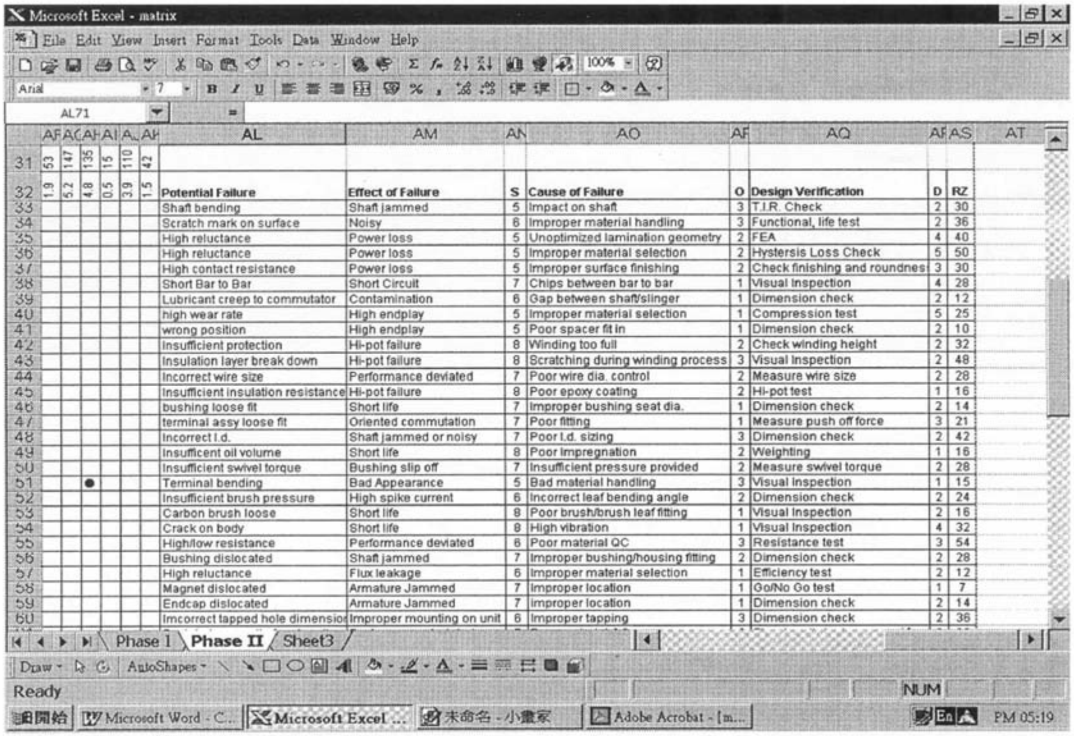


Figure 14. Assessment on function–cost.



	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
31	53	147	135	15	110	42								
32	1.9	5.2	4.8	0.5	3.9	1.5	Potential Failure	Effect of Failure	S	Cause of Failure	O	Design Verification	D	RZ
33							Shaft bending	Shaft jammed	5	Impact on shaft	3	T.I.R. Check	2	30
34							Scratch mark on surface	Noisy	6	Improper material handling	3	Functional, life test	2	36
35							High reluctance	Power loss	5	Unoptimized lamination geometry	2	FEA	4	40
36							High reluctance	Power loss	5	Improper material selection	2	Hystersis Loss Check	5	50
37							High contact resistance	Power loss	5	Improper surface finishing	2	Check finishing and roundnes	3	30
38							Short Bar to Bar	Short Circuit	7	Chips between bar to bar	1	Visual Inspection	4	28
39							Lubricant creep to commutator	Contamination	6	Gap between shaft/slinger	1	Dimension check	2	12
40							high wear rate	High endplay	5	Improper material selection	1	Compression test	5	25
41							wrong position	High endplay	5	Poor spacer fit in	1	Dimension check	2	10
42							Insufficient protection	Hi-pot failure	8	Winding too full	2	Check winding height	2	32
43							Insulation layer break down	Hi-pot failure	8	Scratching during winding process	3	Visual Inspection	2	48
44							Incorrect wire size	Performance deviated	7	Poor wire dia. control	2	Measure wire size	2	28
45							Insufficient insulation resistance	Hi-pot failure	8	Poor epoxy coating	2	Hi-pot test	1	16
46							bushing loose fit	Short life	7	Improper bushing seat dia.	1	Dimension check	2	14
47							terminal assy loose fit	Oriented commutation	7	Poor fitting	1	Measure push off force	3	21
48							Incorrect I.d.	Shaft jammed or noisy	7	Poor I.d. sizing	3	Dimension check	2	42
49							Insufficent oil volume	Short life	8	Poor impregnation	2	Weighting	1	16
50							Insufficient swivel torque	Bushing slip off	7	Insufficient pressure provided	2	Measure swivel torque	2	28
51			●				Terminal bending	Bad Appearance	5	Bad material handling	3	Visual Inspection	1	15
52							Insufficient brush pressure	High spike current	6	Incorrect leaf bending angle	2	Dimension check	2	24
53							Carbon brush loose	Short life	8	Poor brush/brush leaf fitting	1	Visual Inspection	2	16
54							Crack on body	Short life	8	High vibration	1	Visual Inspection	4	32
55							High/low resistance	Performance deviated	6	Poor material QC	3	Resistance test	3	54
56							Bushing dislocated	Shaft jammed	7	Improper bushing/housing fitting	2	Dimension check	2	28
57							High reluctance	Flux leakage	6	Improper material selection	1	Efficiency test	2	12
58							Magnet dislocated	Armature Jammed	7	Improper location	1	Go/No Go test	1	7
59							Endcap dislocated	Armature Jammed	7	improper location	1	Dimension check	2	14
60							Imcorrect tapped hole dimensio	Improper mounting on unit	6	Improper tapping	3	Dimension check	2	36

Figure 15. Assessment of design risk level.

development. The model captured three types of quality-based techniques within a single system, namely, quality function deployment (QFD), value engineering (VE) and failure mode and effect analysis (FMEA). The integrated methodology presented is based on the open system architecture for computer integrated manufacturing (CIMOSA) reference model. In addition to the benefits gained from optimizing the product concept in 'total value' perspective, the product design review framework proposed in this article is essential to aid companies in achieving 'design for quality', which aims to build in the qualities in the design rather than to control the qualities in the manufacturing process. The framework has been successfully implemented in a Hong Kong automotive component manufacturer. Figures 11–15 show the implementation of a PMDC (Permanent Magnet Direct Current) micro-motor project. The motor is used to drive the printer cartridge, referring to figure 11. A software system is built according to the framework and it can help the product development team to review the product design in a systematic way. Sample screens of 'assessment of customer requirements and engineering characteristics', 'assessment of design requirements and part characteristics', 'assessment of function-cost', and 'assessment of design risk level' are shown in figures 12–15. The details of this case study as well as the implementation issues are however presented in another article. To conclude, the integrated product design review matrix proposed in this article helps the NPD team not simply to generate customer reports but to understand further their design concepts in terms of quality, cost and reliability aspects.

Acknowledgement

The authors wish to thank the financial support from the Hong Kong Research Grant Council under the CERG fund no. 9040786.

References

Bahill, A.T., Alford, M., Bharathan, K., Clymer, J.R. *et al.*, Design-methods comparison project. *IEEE Transactions on Systems, Man & Cybernetics Part C: Applications and Reviews*, 1998, **28**(1), 80–103.

Bicknell, B.A. and Bicknell, K.D., *The Road Map to Repeatable Success: Using QFD to Implement Change*, 1995 (CRC Press: Boca Raton FL).

Bhote, K.R., A Powerful new tool kit for the 21st century. *National Productivity Review*, 1997, **16**(4), 29–38.

Caillaud, E., Gourc, D., Garcia, L.A. and Crossland, R., Framework for a knowledge-based system for risk management in concurrent engineering. *Concurrent Engineering Research and Applications*, 1999, **7**(3), 257–267.

Chen, S.G., Wu, M.Z. and Li, R.K., Design of a rule-based flexible manufacturing system controller using modified IDEF0 methodology. *International Journal of Production Research*, 1997, **35**(10), 2793–2820.

Chen, Y.M. and Jan, Y.D., Enabling allied concurrent engineering through distributed engineering information management. *Robotics and Computer-Integrated Manufacture*, 2000, **6**(1), 9–27.

Colquhoun, G.J., Gamble, J.D. and Braines, R.W., The use of IDEF0 to link design and manufacture in a CIM environment. *International journal of operations and production management*, 1989, **9**(4), 48–65.

Dembeck, W. and Gibson, D., Integrating the quality assurance function into the new product development process. In *Annual Quality Congress Transactions Proceedigns of the 1999 ASQ's 53rd Annual Quality Congress*. 1999, **24–26 May**, 238–243.

Dorador, J.M. and Young, R.I.M., Application of IDEF0, IDEF3 and UML methodologies in the creation of information models. *International Journal of Computer Integrated Manufacturing*, 2002, *13*(5), 430–445.

Edward, M., *Integrated Product and Process Design and Development*, 1997 (CRC Press: Boca Raton FL, 1997 ISBN 0849384834)

ESPRIT Consortium AMICE, *CIMOSA: Open System Architecture for CIM*, 1991 (Springer-Verlag: Berlin).

Hargrove, S.K., A system approach to fixture planning and design. *International Journal of Advance Manufacturing Technology*, 1995, **10**, 169–182.

Herder, P.M. and Weijnen, M.P.C., Concurrent engineering approach to chemical process design. *International Journal of Production Economics*, 2000, **64**(1), 311–318.

Kara, S., Kayis, B. and Kaebernick, H., Modelling concurrent engineering projects under uncertainty. *Concurrent Engineering Research and Applications*, 1999, **7**(3), 269–274.

Ke, H.Y., Sampling plans for vehicle component reliability verification. *Quality and Reliability Engineering International*, 1999, **15**(5), 363–368.

Lin, Z.C. and Chow, J.J., Integration planning model of IDEF0 and STEP product data representation metods in a CMM measuring system. *International Journal of Advanced Manufacturing Technology*, 2001, **17**, 39–53.

Liu, T.I. and Yang, X.M., Design for quality and reliability using expert system and computer spreadsheet. *Journal of the Franklin Institute*, 1999, **336**(7), 1063–1074.

Lu, S.C.Y., Shpitalni, M. and Gadh, R., Virtual and augmented reality technologies for product realization. *CIRP Annals – Manufacturing Technology*, 1999, **48**(2), 471–495.

McDonough III, E.F., Kahn K.B. and Barczak, G., An investigation of the use of global, virtual, and collocated new product development teams. *The Journal of Product Innovation Management*, 2001, **18**, 110–120.

Molina, A. and Bell, R., Reference models for the computer aided support of simultaneous engineering. *International Journal of Computer Integrated Manufacturing*, 2002, **15**(3), 193–213.

Minderhoud, S., Quality and reliability in product creation – extending the traditional approach. *Quality and Reliability Engineering International*, 1999, **15**(6), 417–425.

Prasad, B., Model for optimizing performance based on reliability, lifecycle costs and other measurements. *Production Planning and Control*, 1999, **10**(3), 286–300.

Senin, N., Groppetti, R. and Wallace, D.R., Concurrent assembly planning with generic algorithms. *Robotics and Computer-Integrated Manufacture*, 2000, **16**(1), 65–72.

Skinner, W., *Manufacturing: The Formidable Competitive Weapon*, 1995 (John Wiley & Sons: New York).

Swanstrom, F.M. and Hawke, T., Design for manufacturing and assembly (DFMA): a case study in cost reduction for composite wingtip structures. In *International SAMPE Technical Conference Proceedings of the 1999 31st International SAMPE Technical Conference: 'Advanced Materials and Processes Preparing for the New Millennium*', 1999, 101–113.

Tummala, V.M.R. and Kwok, K.K.Y., *Total Control Methodology: Focusing on Quality Improvement of Processes, products and services*, 2001 (University of Hong Kong: Hong Kong).

Wisnosky, D.E., ICAM-foundation for next generation factories. *Industrial Engineering*, 1987, **4**, 38–45.

Wu, T. and O'Grady, P., Concurrent engineering approach to design for assembly. *Concurrent Engineering Research and Applications*, 1999, **7**(3), 231–243.