Keynote Paper:
The US Automotive Industry and Major Developments of QFD

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ABSTRACT
The automotive companies of the United States were early adopters and major users of QFD. On the one hand, they modestly learnt and actively applied QFD. On the other hand, they suggested and voiced their needs to QFD experts along with their applications. The companies have enjoyed a wide range of benefits from QFD, and, in return, they enhanced the development of QFD. Both the industry and QFD have substantially gained from the interaction. The aim of this paper is to discuss how the US automotive industry evolved QFD for specific areas of application by reviewing some of the projects and cases shared by the companies over the years.

Keywords: Quality function deployment, automotive industry, concurrent engineering, Blitz QFD®, AHP, Modern QFD, ISO 16355

1. Introduction

Quality function deployment (QFD) was founded in Japan in the mid-1960s, the time the formation of companywide quality control (CWQC), or total quality management (TQM), had been almost completed. The focus of QFD was the deployment of the central principles of managing quality into the design office of businesses wishing to differentiate their new products by aligning designs to high priority customer needs. After some years of study and trial practice, the research of Yoji Akao on quality assurance of product design together with the profound work of Shigeru Mizuno on quality management led to the formulation of QFD. By making use of the concepts of "network of quality" and control points, QFD successfully enabled corporations to exercise quality assurance from design all the way down to production. Furthermore, it had also suggested an effective mechanism for implementing the important concepts that emerged from the quality movement, including new QC ideas, policy deployment and cross-functional management. With the aim of satisfying the true needs of customers and putting the focus on improving the design, the build, the production and the delivery, QFD has provided an effective method for doing new product and service development as well as a practical way for generating new, enhanced ideas to improve production processes and operation. The effective quality planning with QFD has greatly helped companies on meeting the ever-increasing competition and keeping the vitality of their business.

The Japanese automotive industry enjoyed spectacular growth in the 1960-70s. In 1968, Japan had successfully climbed up to become the world's second largest automaker. However, the companies had to differentiate themselves against the intense foreign competition before the industry could continue with the export success and make a forward leap. The introduction of QFD had offered the companies with great assistance on strengthening the quality of their products for responding to the challenge. At that time, those automotive manufacturers doing B2B export business were faced with severe competition on low-cost production of other countries. In order to keep their exports growing, the manufacturers increased their efforts on ensuring the quality of their products. The conversion type of deployment had effectively helped the manufacturers convert the buyers' requirements into production specifications so as to assure the technical quality of their products; and, the quality charts that used in the deployment process had greatly facilitated the communication between various departments and brought them together to implement CWQC. At the same time, both the B2B manufacturers and the B2C automakers were in search of methods for improving design quality. The former were required to upgrade their business from providing production services to supplying products while the latter were seriously threatened by the huge inflow of foreign cars to the local market. The automakers, in particular, although had made every effort on expanding their product lines and making frequent model changes, they could, at most, reduce customer dissatisfaction. With QFD, they were able to increase customer satisfaction. The methods for understanding the customer needs and the conversion type of deployment for identifying the important design characteristics enabled them to assure the design quality of their products (Akao & Kogure, 1983).

QFD reached the United States in the early 1980s. The automotive companies there besides were early adopters and major users of QFD, they had also played an influential role in the development of QFD. On the one hand, they modestly learnt and actively applied QFD. On the other hand, they voiced their needs to QFD experts along with their applications. The companies have enjoyed a wide range of benefits from QFD, and, in return, they enhanced the development of QFD. Both the industry and QFD have substantially gained from the interaction. The aim of this paper is to discuss how the US automotive industry evolved QFD for specific areas of application by reviewing some of the projects and cases shared by the companies over the years. It is hoped that the discussion could motivate academics and practitioners on putting QFD into application in various industries and seeking ways to continuously improve QFD.

2. QFD: From Japan Automotive Industry to the US Automotive Industry

Bridgestone Tire was the first company applying QFD. Toyota soon followed because it needed to overcome a quality problem. Although Toyota had successfully introduced its cars to the United States as early as in the mid-1960s, its cars were perceived as low-quality economy cars because they rusted very quickly. To tackle the problem, engineers used the company's LiteAce, a light-duty pickup van, which had some of the more severe rusting problems, to undertake a study using the quality charts Kobe Shipyards of Mitsubishi Heavy Industries put forward in 1972. At the same time, they arranged focus groups to listen to the customers on what they liked and disliked with the van. In regard to the operating environment and the usage of the van, the team was informed on many issues relating to the vehicle door, such as the difficulty of opening the door inside the van when the van was parked uphill and downhill, which, in before, were considered not important. From the encounter with customers, the team had acquired a much better understanding with their needs. Making use of quality charts, the customer needs and requirements were effectively deployed into engineering and manufacturing processes (Guinta & Praizler, 1993). Besides the body and chassis rust and the vehicle door, Toyota had also done some other QFD projects, including one for the sun roof and one for the wipers. The favourable results obtained by Toyota quickly spread QFD among its suppliers, and, eventually to the whole automotive industry.

In the late 1970s, the business game of the US automotive industry drastically changed. Suppliers could no longer earn profit simply by raising the selling price but were required to improve product performance, reduce costs and achieve customer satisfaction. In order to successfully compete in the market, companies refined their focus on quality and put customer satisfaction at top of their agenda (Stratton, 1989). They realized the long-practiced engineering-oriented management was no longer sufficient for performing competitive product development as extra cost and time would be involved if alternations were made after product launch. Engineers possessed technical knowledge for controlling the make and the production quality. However, they might not have much knowledge with the needs of the customers for controlling the design quality of products. The way of digging deeper into the process and getting nearer to the customers, which the Japanese corporations had practiced for twenty years, provided the US automotive companies with the clue. For a tool that would help complete the communication chain from the customers down to the shop floor production with the purpose of achieving quality, QFD caught the attention of the US automotive companies (Ginder & Quinn, 1988; McElroy, 1987, 1989). Furthermore, the focus on understanding the customer needs and priorities as well as the systematic translation into high priority product design and production requirements could lead to a significant reduction of development time and costs of vehicles. Yoji Akao first briefed the US automotive companies on the benefits experienced at Toyota in 1985; and, over the subsequent eight to ten years, Japanese QFD experts were invited to go to the United States to give lectures and conduct training. Ford was the first, followed by General Motors and Chrysler. Ford also insisted their suppliers on applying QFD, mimicking the Japanese approach.

3. The Four-Phase Model

At the initial stage, pre-planning matrix and house of quality (HOQ), introduced by Don Clausing after working with Dr. Makabe of Fuji Xerox and later promoted by American Supplier Institute (ASI), were the primary tools used for QFD operation. The operation process usually started with first completing the pre-planning matrix for strategy formulation and followed by deploying the customer requirements into design requirements using a quality table, often called the house of quality (HOQ) due to its shape, that shown in Figure 1.

Upon mastering the skills of the basic operation tools, ASI developed the Four Phase Vehicle Development Process, commonly known as the 4-Phase Model (Figure 2) – a customized version of QFD for the automotive industry. It was a significant simplification of the multi-stage, comprehensive QFD approach developed by Yoji Akao and Shigeru Mizuno. Displaying the concept in the form of a diagram, the model provided the automotive companies with a general guideline for doing product and concurrent manufacturing development.

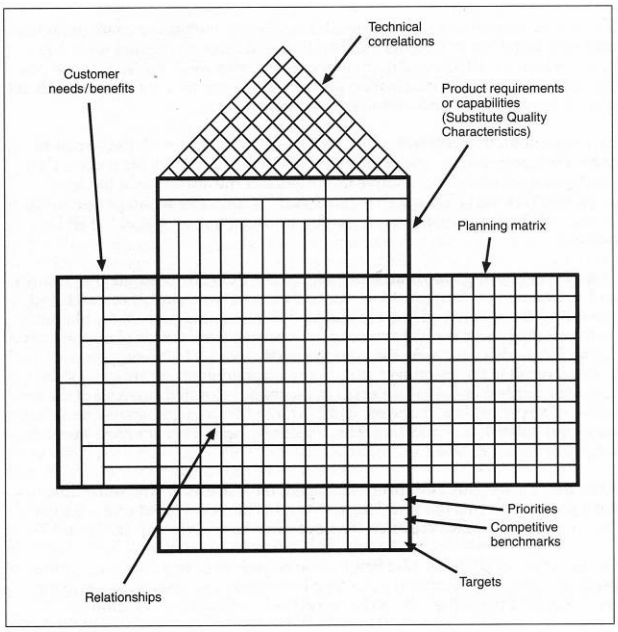

Figure 1: The house of quality

Adopted from: Cohen, L. (1996). *Quality Function Deployment: How to Make QFD Work for You,* Addison Welsey, Diagram 4-1.

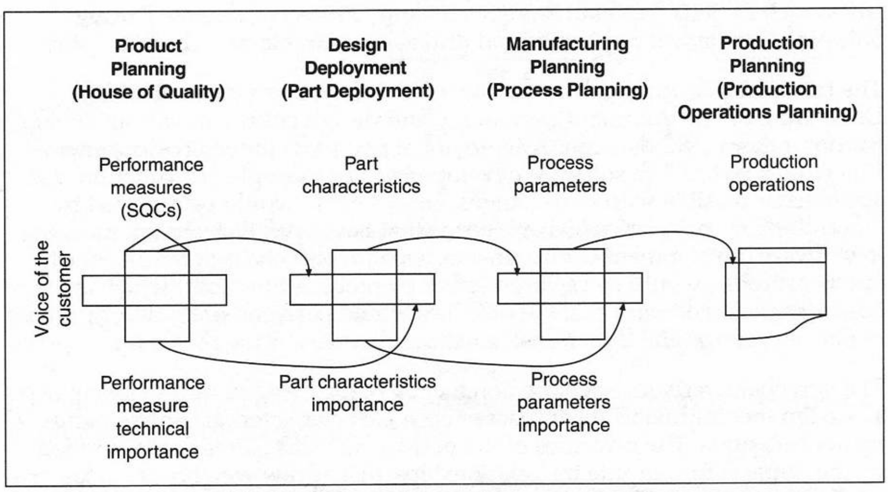

Figure 2: The 4-Phase Model

Adopted from: Cohen, L. (1996). *Quality Function Deployment: How to Make QFD Work for You,* Addison Welsey, Diagram 18-1.

As the principle of meeting customer needs is important to performing successful change, therefore, for almost every of the early QFD cases, the team placed extra focus on identifying who were the customers and exploring their requirements. For some cases, the team continued with deploying the requirements into parts characteristics, manufacturing operations and production requirements to complete all four phases. Whilst exercising matrix-to-matrix deployment was a major purpose and key feature of the early applications, the automotive companies did not always exactly follow the flow or the steps of the 4-Phase Model for doing QFD. In many cases, they adjusted or modified it for meeting their own conditions and purposes. Below are some examples.

- In a joint project on improving the vehicle wiring system conducted by Electro-Wire and Ford, the wants of service mechanics of dealers and those of workers of assembly plant were deployed into design requirements using two separate HOQs. When the want of "eliminate hazardous routing" was found ranked highest of both customer groups, a new set of matrices was started to deploy this important want into manufacture and assembly requirements for improving the routing (Carter et al. 1989).
- For the development of the junction box for a Ford's light truck program of AFL Automotive, 3-Phased CQFD (Concurrent QFD) was applied to help implement the project. The application was termed as "CQFD" instead of "QFD" because QFD was done concurrently with product design rather than before product design. Upon completed Phase I, a "disposition matrix" was constructed to determine which of the tertiary HOWs were going to be put into Parts Deployment of Phase II. When came to Process Deployment of Phase III, the team added customer wants into the operation as well (Fernandez et al. 1994).
- Milliken Industries and Northern Rubber jointly did a QFD project on air brake chamber diaphragm. While following the flow of the 4-Phase Model, the team constructed a full customer hierarchy and added in functional analysis for achieving a full understanding with the requirements and critical parameters of both companies (Wootton & Newbold, 1994).
- The Dunton Technical Centre in UK of Ford Motor had shared a case on using Phases I and II of the 4-Phase Model to design the side door of family vehicles for optimizing customer comfort when opening and closing the door. After identified the design characteristics in Phase II, the team members prepared a morphological chart containing the drawings of solutions and sub-solutions for addressing each product function to generate concepts. They then used a simple 2-way matrix to compare the generated concepts against the predefined criteria for making selection (Miller et al. 2005).

4. Facilitate QFD Operation with Incorporating Necessary Tools and Processes

For projects that aimed at improving current products or developing new products, the teams were commonly asked to yield some ideas or even to present the prototypes. When came to the stage of design formation, they would use various kinds of essential testing methods and quantitative tools to assist them on providing evidence for supporting their suggestions. Here are some examples.

- For the project on designing the belt of the front end accessory drive (FEAD) system of Ford Motor, simulation programs and design of experiments were added to executing the series of matrices (Ahoor, 1989).
- In a truck project deploying the design characteristic of "closing effort" into components, processes and production of General Motors, Pugh analysis and variation simulation modeling were used for concept selection. Besides, a variety of tools, including Fault Tree Analysis (FTA), Taguchi parameter design, Taguchi Loss Function (TLF), robust system design, Design for Assembly (DFA), Design Failure Mode Analysis (DFMA) and competitive benchmarking were used for seeking optimization (Biondo, 1991).

Making selection among a given range of options is a process very common in product development. In most of the cases, the boss or the expert team would make the selection. However, to be more objective, more and more cases would make use of the customer requirements or the design requirements that derived as the "ruler" to measure the effectiveness of the alternatives for option selection.

- A project team of Eaton constructed a quality table and used the identified important design features as the basis to assess seven different kinds of compressors for vehicle air conditioning system, though the customer requirements were brainstormed by the team members instead of actively collected from the customers (Kenny et al. 1989.
- In the project on developing a leak detector of Varian Vacuum Products, the team constructed a function matrix to explore the basic functionality of leak detector in regard to the customer requirements. Upon establishing the selection criteria, a concept selection matrix was used to choose one out of the three proposed concepts which would most likely satisfy the needs of customers and business strategy (Leeds & Frasso, 1993).
- Volvo applied QFD in a project on concept development for future vehicle. Upon compiling a full list of critical design characteristics addressing the legal requirements for emission and fuel economy, the target customer requirements and the corporate requirements for business and product strategy, a matrix was used to evaluate the available alternatives. The matrix was found not only useful for concept selection but also assisted on generating more alternatives and attempting to find ways to eliminate misusing the strongest designs or to generate new ideas that were inherently superior to any of the initial designs (Voegele, 1993).
- In the fuel rail project of Visteon, the team used 2-way matrices to make assessment for each of the 17 available options to identify a manufacturing process which was capable of meeting the needs of all six engine families (Vinarcik, 1999).

Shortcomings with many of the automotive companies led applications of QFD were seen, in particular where the company's specification was used instead of the requirements, and where the customer was limited to the company's customer rather than the company's customer plus the end users of the vehicle, which had been the original focus of Akao and Mizuno's QFD.

5. Voice Their Needs to QFD Experts

After applied QFD for some years, the US automotive companies had found two problems that greatly limited their full application of QFD. The first problem was the considerable amount of time required for completing the whole set of deployments. In the face of ever shorter time and intense competitive pressure as well as constrained financial and human resources, many attempts could not complete all four phases. In some cases, the tedious work involved in the matrix-to-matrix deployments sometimes even had scared the teams. The second problem was the low degree of accuracy of the produced priorities. Concept development and selection is a core step of product development of the automotive industry. The importance of this step could be reflected from the addition of value analysis/value engineering to the function analysis of QFD in preparing design proposals for a brake system of Hayes Brake and putting Pugh concept selection as the central feature of the overall product development process of Chrysler (Dika & Begley, 1991; Dimsey & Mazur, 2002). Besides preparing design proposals for winning orders, investment involved in automotive prototyping, technology and manufacturing development was always huge. There was no room for making any wrong choice because of mathematically invalid calculation.

Richard Zultner (1997) introduced Blitz QFD® (Figure 3) to solve the time problem by exploiting the benefits of QFD within time and resource poor agile software development environments. With making deployment across multiple columns of a spreadsheet, the full range of compact tables rather than matrices could considerably shorten the time required by the process. The tables help focus on a small number of stakeholders' and product functional requirements. Zultner also introduced analytical hierarchy process (AHP) to provide a more mathematically-sound relative prioritization approach combined with a hierarchical analysis of needs and goals. AHP, formulated by Saaty, is a decision making model from which the priorities that derived could give a proportionate ordering of the different possible outcomes to which one can allocate resources in an optimal way (2007). The incorporation of analytic hierarchy process (AHP) to QFD greatly helps provide reliable data for decision making. Furthermore, as QFD is not just doing a HOQ but an unbroken continuity of prioritization is required for performing effective operation, AHP complements the operation of QFD with a quantitative mechanism for generating and transferring accurate priority data throughout the whole process, which, in many cases, involves a chain of deployments and multiple matrices.

The needs of the users with QFD have brought about a marked improvement to QFD. The formulation of Blitz QFD® and the corporation of analytic hierarchy process (AHP) significantly raise the operation efficiency and the application effectiveness of QFD. Under the supervision of Yoji Akao, Glenn Mazur and Richard Zultner developed this approach to apply to all phases of comprehensive QFD, which is described as 'Modern QFD'. The project on designing and selecting a brake system sensor of TRW Automotive was one that applied Modern QFD. From the first step of clarifying the business goals down to the final step of selecting a concept for the sensor, normalized scale and AHP were used for the involved quantification while Blitz QFD® and affinity diagramming were used to process the customer needs (Johnson & Mazur, 2008).

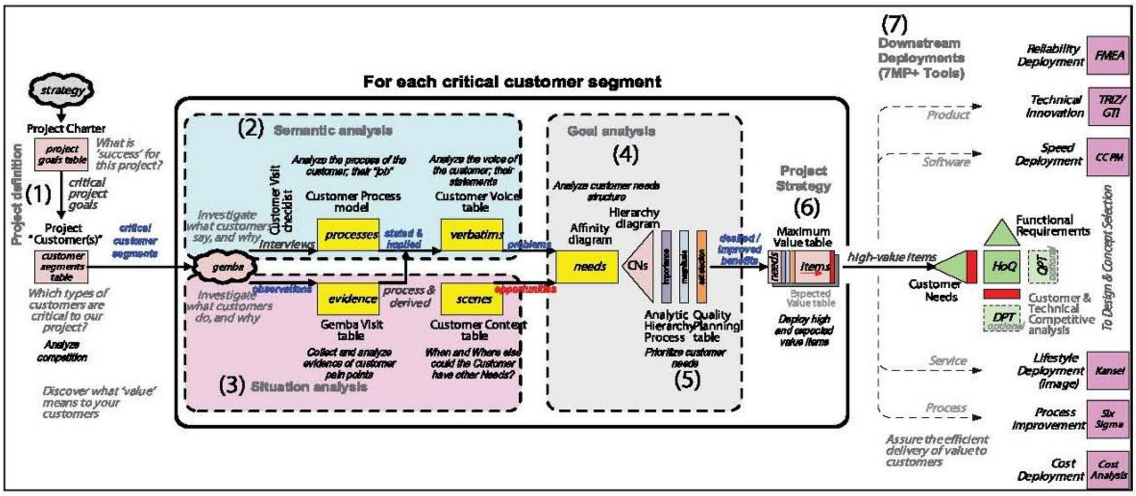

Figure 3: Blitz QFD®

Adopted from: QFD Black Belt® Workshop Material 2016, Boise, Idaho, USA

Modern QFD has already become a main stream of QFD application in nowadays field practice, and, the approach has been captured in a descriptive ISO Standard for best practices in QFD, viz. ISO 16355.

6. Conclusion

Both the US automotive companies and QFD had developed through the industrial applications. Whilst the companies had learnt some core principles of QFD and acquired the knowledge for building their own product development methods and systems, further enhancements for the agile software development industry led to significant progress in the development of more focused and effective forms of Modern QFD that accelerated the deployment of comprehensive QFD approaches originally seen in Japan. The US automotive industry and the QFD development approaches both benefited.

One may view the rise and fall of QFD application in the US automotive industry and subsequently agile software industries as the life cycle of a product. The introduction stage was the time large and small automotive companies all rushed to learning it. After the widespread growth stage and enhancements made in the mature stage, it is now the decline and extension stage. However, QFD is not a product; and, it is not a fad practice. Firmly grounded on the basic principles of quality management and quality assured and concurrent design, QFD is a generic methodology of organic nature. The place and the product sector of application might have changed, but QFD is still developing continuously to assist automotive, software, medical device and service companies in making significant improvements and gaining competitiveness.

References

Ahoor, R. (1989). Front end accessory drive. *Transactions from A Symposium on Quality Function Deployment,* Novi, Michigan, 195-232.

Akao, Y., & Kogure, M. (1983). Quality function deployment and CWQC in Japan: A strategy for assuring that quality is built into new products. *Quality Progress*, October, 25-29.

Biondo, B. (1991). Application of QFD and other quality tools to a trunk system. *Transactions from The 3rd Symposium on Quality Function Deployment,* Novi, Michigan, 502-521.

Carter, D., Hasenstab, K., Schafer, S., & Uroda, B. (1989). Vehicle wiring QFD. *Transactions from A Symposium on Quality Function Deployment,* Novi, Michigan, 127-143.

Dika, R. J., & Begley, R. L. (1991). Concept development through teamwork – Working for quality, cost, weight and investment. *Transactions from The 3rd Symposium on Quality Function Deployment,* Novi, Michigan, 431-449.

Dimsey, J., & Mazur, G. (2002). QFD to direct value engineering in the design of a brake system. *Transactions from The 14th Symposium on Quality Function Deployment,* Novi, Michigan, 23-43.

Fernandez, J. E., Chamberlin, J. L., Kramer, E. G., Broomall, J. H., Rori, H. A., & Begley, R. L. (1994). Making the Neon fun to drive. *Transactions from The 6th Symposium on Quality Function Deployment,* Novi, Michigan, 483-508.

Ginder, D. A., & Quinn, W. B. (1988). Quality function deployment – Customer driven engineering. *SAE Technical Paper #881334*.

Guinta, L. R., & Praizler, N. C. (1993). *The QFD Book: The Team Approach to Solving Problems and Satisfying Customers through Quality Function Deployment,* American Management Association.

Johnson, C. M., & Mazur, G. H. (2008). Value based product development – Using QFD and AHP to identify, prioritize, and align key customer needs and business goals. *Transactions from The 20th Symposium on Quality Function Deployment,* Santa Fe, New Mexico, 23-39.

Kenny, A. A., Malone, P. G., Malone, P. J., Torrence, R., & Seals, D. (1989). Evaluation of a/c system using the quality function deployment technique, *International Congress and Exposition,* Detriot, Michigan.

Leeds, A. J., & Frasso, P. J. (1993). Aligning a concurrent product development process using Momentum® QFD: A case study in letting the voice of the customer drive the conceptualization of a new leak detector. *Transactions from The 5th Symposium on Quality Function Deployment,* Novi, Michigan, 127-143.

Mazur, G. (2015). ISO 16355 – The international standard for QFD. *The Paper Collection of The 21st International Symposium on Quality Function Deployment,* 10-21.

McElroy, J. (1987). For whom are we building cars? Let's get rid of "opinioneering" and start building cars that meet the voice of the customer! *Automotive Industries,* June, pp. 68-70.

McElroy, J. (1989). QFD building the house of quality: Why and how quality function deployment is spreading through the automotive industry. *Automotive Industries,* January, pp. 30-32.

Miller, K., Brand, C., Heathcote, N., & Rutter, B. (2005). Quality function deployment and its application to automotive door design. *Proc. IMechE, Vol. 219,* Part D: J. Automobile Engineering.

Saaty, T.L. (2007). The analytic hierarchy process: How to measure intangibles in a meaningful way side by side with tangibles. *Transactions from The International Symposium on QFD 2007-Williamsburg & The 19th Symposium on Quality Function Deployment*, 113-135.

Stratton, B. (1989). The refined focus of automotive quality. *Quality Progress,* October, 47-50.

Vinarcik, E. J. (1999). Quality function deployment for manufacturing technology assessment. *Transactions from The 11th Symposium on Quality Function Deployment,* Novi, Michigan, 31-57.

Voegele, S. (1993). Volvo's E.C.C. (environmental concept car): QFD applied to a future concept car. *Transactions from The 5th Symposium on Quality Function Deployment,* Novi, Michigan, 291-306.

Wootton, D. B., & Newbold, J. (1994). QFD study on brake chamber diaphragm. *Transactions from The 6th Symposium on Quality Function Deployment,* Novi, Michigan, 473-482.

Zultner, R. E. (1997). Managing software development projects better with Blitz QFD. *Transactions from The 9th Symposium on Quality Function Deployment,* Novi, Michigan, 391-402.

Authors' Backgrounds

	***Dr. Catherine Y. P. Chan*** *is certified QFD Black Belt®. She is the President of Hong Kong QFD Association, Secretary General of Asia QFD Association and committee member of International Council for QFD. With the aim of sharing the knowledge and experience she has gained since the start of her research on QFD in the early 2000s, she focuses on and actively participates in promoting QFD in Hong Kong and South East Asia.*
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	***Dr. Kim Stansfield*** *is Akao Prize Winner 2016. Following Bachelors, Masters and Doctorate degrees in materials science and technology, Kim started his career in the Composites Group of the UK's Royal Aerospace Establishment before moving to Lucas Engineering and Systems in the early 1990s to work on development of an automated design and manufacturing system for complex composite components. Here he learned Japanese TQM methods including QFD. Over the following 20 years he worked in automotive and aerospace control systems and subsequently large Enterprise IT Systems applying QFD and DFSS approaches to development. Later at the Energy Technologies Institute, he applied modern QFD methods to support design and development of sustainable (economic and environmental) energy programmes. In 2016 he joined Warwick University WMG where he is an Associate Professor teaching systems engineering, advanced quality methods and business improvement processes on undergraduate, post graduate and professional executive programmes. He has been the UK representative for the development of the ISO 16355 standard for QFD since 2010. He also has joined the recently formed INCOSE Working Group on 'Systems Engineering Quality Management'. He is a Chartered Engineer, a member of the IET and INCOSE and a certified QFD Black Belt®.*