APPLICATION OF QFD INTO THE DESIGN PROCESS OF A SMALL JOB SHOP

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Abstract

This was a case study involving the application of Quality Function Deployment (QFD) into the design process at Reynolds & Co., a small job shop in Terre Haute, IN, USA. The company's work is customer-oriented. The objectives of the research were to find the applicable QFD concepts and to reduce the average design time or number of design changes in the design process. The House of Quality (HoQ) was modified for organizational use in order to identify goals and priorities of the company. The case study was successful in providing research into the implementation of QFD concepts to improve the design process of a small job shop. However, the design time and the design changes were not decreased significantly. It was important to discover that job shops better understand their customers through direct interaction than do large consumer-based companies.

Introduction

Quality Function Deployment (QFD) is a compilation of the product design and its manufacture, which includes the customer requirements as well as the design/engineering requirements. QFD is "a tool for collecting and organizing the required information needed to complete the operational quality planning process" [1]. Ternimko [2] stated that QFD is not a replacement for an existing design process. Instead, it would work with the design process in place and provide a more efficient system through the improvement of customer perceived quality. QFD was first developed in Japan [3]. QFD implementation generally results in significant improvements in both product design and the development process [4]. A variety of approaches to QFD have been implemented in the US with varying degrees of success [5].

The present work is a case study of implementing the necessary QFD concepts into the design process at Reynolds & Co., located in Terre Haute, IN, USA. A portion of this work was included in Thomson et al. [6]. Reynolds employs approximately 25 people, most of whom are machinists and fabricators by trade. This is a custom manufacturer of components and special machinery for the plastics industry as well as other types of industry around Indiana and the United States (business to business). Thus, this is a small "make-to-order" company, which is different from a typical high-volume "build-to-stock" or consumer-based company [7].

For purposes of this study, the phrase "design process" was used to describe the method of converting the customer requests into manufacturable products. The customer requests of the design process at Reynolds may include any of the following types. The first type of customer request is an outside customer order, where the customer provides the specifications, or prints, and details for the product/component. The second type of customer request is an outside customer order for a product/component, where Reynolds & Co. provides the specifications for the drawing design and the customer provides the requirements. The third type of customer request is where an outside customer provides a part or component to be reverse-engineered/designed. The fourth type of customer request is the internal-customer type, where the products are manufactured after the design process is complete. These are all customers of the design process.

There exists an extensive amount of literature on QFD implementation in a high-volume or consumer-based manufacturing environment, but very little on job shops. This was the motivation behind this study. Specific objectives of the research were to 1) find the QFD concepts that apply to the improvement of this specific job-shop design process, 2) reduce the average design time, and 3) decrease the number of design changes. The design process was analyzed by averaging the design time and the number of design changes before and after the implementation of QFD strategies/concepts.

Review of Related Literature

In this section, a review of related literature on Quality Function Deployment and job shops is presented.

In the late 1960's in Japan, Professors Mizuno and Akao [8] developed a quality-assurance concept of designing customer satisfaction into a product and called this Quality Function Deployment (QFD). QFD helps companies identify real customer requirements and translates these requirements into product features, engineering specifications, and manufacturing details. The product can then be produced to satisfy the customer. This means that the customer-perceived quality is present before the manufacturing even gets started. QFD is proactive since the vast majority of the design and marketing problems are handled before manufacturing begins; traditional quality control is reactive as it focuses on fixing problems once production has begun. QFD was applied on its first large-scale application in 1966 at Bridgestone Tire in Japan by Oshiumi using fishbone diagrams to better accommodate customer needs into Bridgestone tires [8]. Mitsubishi Heavy Industry used QFD concepts to aid in the design of an oil tanker in 1972. In the following years, Toyota Motors used it to revolutionize the design process of new automotive vehicles [9]. Fishbone diagrams that were initially used were updated and transformed into a spreadsheet/matrix format to aid in the complexity of the Mitsubishi oil tanker design [8]. During the same period, Ishihara [8] introduced Value Engineering concepts to explain business functions necessary to ensure quality of the design process. As a result of the combination of these emerging concepts, QFD became the comprehensive quality-design system for both product and business process [8]. Jiang et al. [10] and Shiu et al. [11] modified QFD structure so that it can effectively be used in contract manufacturing and new-product development cycle, respectively.

QFD consists of two components: quality and function that are deployed into the design process [12]. Quality deployment brings the customer's voice into the design process, whereas function deployment brings functional specialists from different organizational functions and units into the design-to-manufacturing process. QFD process involves product planning, product design, process planning, and process control [13]. Akao [14] defines quality function deployment as converting the consumers' demands into 'quality characteristics' and developing a design quality for the finished product by systematically deploying the relationships between demands and characteristics, starting with the quality of each functional component and extending the deployment to the quality of each process. The overall quality of the product will be formed through this network of relationships. QFD is a compilation of planning and analyzing tools. Some of these tools are charts and graphs but the best known is the house of quality (HoQ). The HoQ chart [5], [15], [16] is used to analyze customer requirements and the engineering/design requirements and the relationships that exist between them. Akao and Oshiumi introduced the HoQ in the 1966 Bridgestone Tire project [8]. However, the HoQ is not a necessity for the implementation of QFD, particularly in technology-driven QFDs and cost-reduction-driven QFDs [2], [8], [16].

Another QFD documentation requirement deals with the organization and company goals. These can be broken into business or organizational goals, product goals, and project goals [17]. Goals are organized on a radar chart [1], [2]. The purpose of a radar chart is to list the company goals around the perimeter of the circle and compare the findings from before and after a change. The radar chart data is gathered by interviews with the organizational leaders or by customer inputs. The metrics of the radar chart are that the closer the objective is to the outside of the chart the better the company is in this aspect [2]. The goal of the radar chart was to even out the goals with respect to one another. The radar chart should be round if the company's goals were met congruently [18]. The next form of documentation is in the form of questions that are geared to stimulate the customer's requirements during the review of the customer's requests, which may take place in the customer's plant [17].

The term "job shop" is used to refer to all types of custom manufacturing, make-to-order businesses—including machine shops—that meet the following criteria [7]: 1) Produce on an order-by-order basis to meet customers' specifications—order driven; 2) Secure work through a bidding process; 3) Serve other companies and/or distributors as opposed to customers or end-users; and 4) Serve as service companies. Job shops do not function like a typical high-volume build-to-stock company [7]. The job shop can be very diverse and can rapidly adapt to changes in production. A change can be made to a customer's order in a matter of minutes, typically, where a high-volume build-to-stock company thrives on stability. And should a change occur in a customer's order, the change may take days to weeks to be made. The job-shop process of design is focused on the following objectives: function, durability, appearance, and cost [19]. These design objectives are customer-driven. This means that the customer must approve, otherwise the design is not effective. Engineering objectives are requirements such as material strength, reliability, and design parameters. In addition, the designer has the job of designing with manufacturing in mind. This is achieved through simplicity of design, standard materials, and liberal tolerances [19]. Competition is similar between the consumer-based production manufacturer and the small job shop. The presentation of customer-perceived quality and the price of the product is subject to review by the customer. This review will influence the buying patterns of the customer.

Reinforcement for the rationale of this study includes the fact that United States companies are facing tough competition from overseas competitors [19]. Ternimko [2] states that QFD strategies aim at reducing cost by understanding the customer requirements better and therefore providing improved value to the customer. Improved value for the customer is a factor of achieving customer requirements such as cost, function and aesthetics.

QFD Implementation at Reynolds

This case study was conducted from December 2004 through April 2005. An analysis of the Reynolds' design process was conducted in December 2004. There were four types of customer requests for the design process at Reynolds as outlined in the introduction section. The average design time and the number of design changes for October and November of 2004 were measured.

Next was the QFD implementation phase, which was conducted during December 2004 and January 2005. Reynolds' goals were determined by interviews with the management and by research into the driving factors of the job-shop environment. Initial measurements of how the company was meeting its goals were obtained from interviews with the management. These measurements were compared with the measurements obtained from the customer surveys. The survey questions were prepared to capture customer perceptions of the Reynolds' goals and design process.

Customer	**Description**	**Relationship Goals / Potential**
Company 1	Blown film, printing, converting	1. Increase sales and design potential 2. Building improvement
Company 2	Blown film, cast film, printing, converting	1. Increase communication / design
Company 3	Closure Systems	1. Increase communication 2. Provide better service
Company 4	Cast Film	1. Design and build sheet dies
Company 5	Recycling plastics	1. Design and build blades 2. Design and build other auxiliary equipment
Company 6	Blown Film	1. Sales potential
Company 7	Aluminum Sheeting	1. Increase communication 2. Increase sales
Company 8	Steel Sheeting	1. Provide better service 2. Improve communication

Figure 1. Customer prioritization chart

QFD then required Reynolds to prioritize their customer list according to the value of the customer related to the company's goals. The customer-prioritization chart is shown in Figure 1. This prioritization was assembled through interviews with the management. The next form of documentation created was a list of questions that were designed to stimulate the customer's requirements during the review of the customer's requests, which could take place over the phone or face-to-face. The chart of customer requirements stimulating questions is shown in Figure 2. Understanding the customer requirements and stimulating these requirements may be a problem associated with the high-production consumer-based company. Small job shops, on the other hand, know exactly who their customers are because they are make-to-order companies.

Questions to Stimulate Customer Requirements:
JOB NUMBER: _______-______ DATE: _____________

Question:	Answer:
1. Part / Mechanism description (part number, drawing number, physical size)	
2. Function (type of motion, how it works)	
3. Critical tolerances / fits	
4. Materials (Type & Hardness)	
5. Physical Size & Weight (Can we haul it & Machine it)	
6. Delivery (OT or Regular)	
7. Machining requirements (Type of machining)	
8. Contact name, phone, company	
9. Location of pickup / delivery	
10. Cost / pricing (P.O. Number)	

Figure 2. Chart to stimulate customer requirements

The next form of design-process documentation was to create a sheet or drawing to list the customer requirements as shown in Figure 3. This form of documentation was substantial in the form of time-savings during manufacturing and improved communication between the design department and the manufacturing department. This improved communication eliminated some rework time and additional design time that were not necessary to complete the job. An example of a communication error that occurred frequently because of lack of proper design documentation was when a part that was acceptable with saw-cut ends and a tolerance of plus or minus 1/32" was frequently machined to a tolerance of plus or minus five thousandths. The customer was not willing to pay extra for the time required to machine the part to this tighter tolerance; therefore, the profit margin was eroded.

Drawing / Manufacturing Information	
Gibbs Cam (Name & Location)	
Employee Number	
Machine Number	
Saw Cut Length Information	
Machining Notes	
Fixture Information	

Figure 3. Drawing / manufacturing documentation

QFD breaks down customer requirements into different categories, each having a different expectation and satisfaction type. These requirements can be classified as the expected, normal, and exciting requirements [17], [20]. The customer requirements were brought to the manufacturing process by including them on the drawings/prints, according to the chart in Figure 3. The process of following customer requirements helped Reynolds to focus on customer-perceived quality and, therefore, provide better value to the customer.

According to QFD concepts, the customer requirements need to be evaluated in order to transform them into the design requirements and rank their importance. QFD recommends using the house of quality (HoQ) chart for product design. The HoQ was simplified for job-shop usage [20]. But, the HoQ was not helpful on the Reynolds' job because the amount of time required to construct a HoQ was substantially more than the entire job had initially required. Therefore, the HoQ was revised to make it an organizational improvement chart. The surveys were used to accomplish this objective. The revised HoQ chart is shown in Figure 4. The objective of using the HoQ for the organization was effective in understanding the customer requirements associated with the organizational standing of the job-shop environment. The design goals determined through interviews with the management of Reynolds were service, delivery, price, dimensional accuracy, and overall quality.

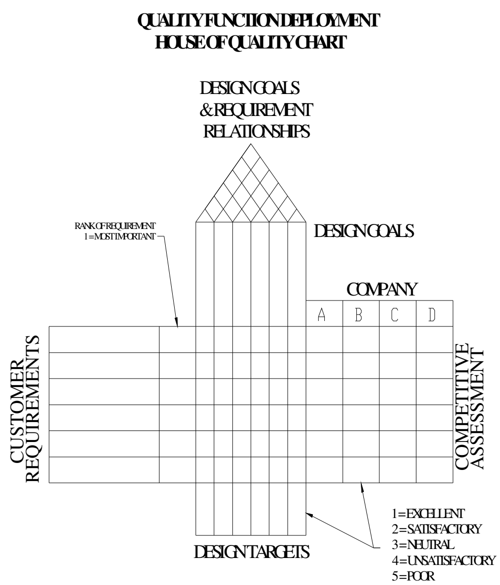

Figure 4. Organizational House of Quality chart

The progression of the implementation meant new ways of keeping track and documenting processes in order to save time and relieve confusion. In this regard, a document was created to list the common items ordered from certain vendors. The timeline for implementation of the QFD concepts (December 2004 through January 2005) was considered exempt from the before-and-after comparisons. The period before the QFD implementation was October and November 2004. The period of February and March 2005 was after the implementation. The data collection was focused on measuring the average design time and the number of design changes. Data was collected by searching Reynolds' job listings and collecting the design time out of the total time incurred by each job that started before or after this time period.

Results

In this section, results of the QFD implementation are summarized.

Data for the time taken and the number of design changes for the design jobs that occurred during October through November 2004 were collected. Descriptive statistics for the design time and number of design changes are presented in Table 1 and Table 2, respectively. Raw data and other details are given by Thomson [20]. The total number of jobs with complete information was 337. The mean design time was 0.9325 hours with a median of 0.25 hours, and a standard deviation of 1.98 hours. The mean number of design changes that occurred was 0.1098, with a median of 0.0 (no design change required after the design), and a standard deviation of 0.683. The design-time and design-change data for the period February through March, 2005, as the post implementation stage of the study are given by Thomson [20]. There were 344 jobs in total. The mean design time was 0.843 hours, with a median of 0.25 hours, and a standard deviation of 1.91 hours. The mean number of design changes was 0.0727, with a median of 0.0, and a standard deviation of 0.4983. The data for design-time and design-change were found to be independent and random [20].

Table 1. Descriptive statistics for design time in hours from October through November, 2004

Statistics

Design Time (October-November 2004)

N	Valid	337
	Missing	7
Mean		.9325
Median		.2500
Mode		.25
Std. Deviation		1.98105
Variance		3.92456
Skewness		5.689
Std. Error of Skewness		.133
Kurtosis		45.343
Std. Error of Kurtosis		.265
Minimum		.00
Maximum		22.00

Dependant-sample T-Tests [21] were used to compare both the design-time and design-change data before and after the QFD implementation. The critical T value for a two-tailed test at a 95% confidence level and 336 degrees of freedom was 1.96 [21]. The T-Tests provided T values of 0.527 and 0.762 for the design time and design changes, respectively. Both were lower than 1.96. Therefore, the design time and number of design changes before and after the implementation were not statistically different.

Table 2. Descriptive statistics for design changes from October through November, 2004

Statistics

Design Changes (October-November 2004)

N	Valid	337
	Missing	7
Mean		.1098
Median		.0000
Mode		.00
Std. Deviation		.68343
Variance		.46708
Skewness		7.793
Std. Error of Skewness		.133
Kurtosis		69.812
Std. Error of Kurtosis		.265
Minimum		.00
Maximum		8.00

The next part of the study was to analyze the surveys sent to the customers to see how the customers viewed Reynolds in terms of service, delivery, price, dimensional accuracy, overall quality, and how well the company satisfied their goals and requirements. In order to satisfy the policies related to Research Involving Human Subjects, an exemption from the Institutional Review Board (IRB) was obtained. The IRB stated that in order to keep the survey anonymous, they must stay local so that the Post Office stamps on the return envelopes would not give away the location of the survey respondent. Therefore, only local companies were selected to represent Reynolds' customer base. Seventeen survey-responses were received. The mean values for all customer requirements were found to be between 4.65 and 4.82 on a scale of 5; the only exception was for price (3.94), which was considerably lower and had a higher standard deviation than the other customer requirements. However, this may be influenced by a bias in the respondents.

The management at Reynolds thought that they were satisfactory on price, service, delivery, and dimensional accuracy; and neutral on overall quality, as displayed in the radar chart of Figure 5. The customers, however, rated all factors as excellent and price as satisfactory, as depicted in the radar chart of Figure 6. This, again, emphasizes the importance of the drawing or some kind of documentation, as shown in Figure 3, for manufacturing to avoid making a product more precise and, in turn, more expensive than what the customer wants. The findings from the survey were then analyzed in the form of the House of Quality, as shown in Figure 7. The HoQ was a means of discovering a relationship between the organizational goals and common customer requirements.

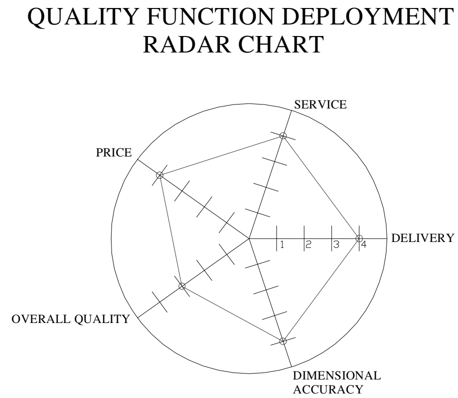

Figure 5. Radar chart displaying the organizational goals based on the management interviews

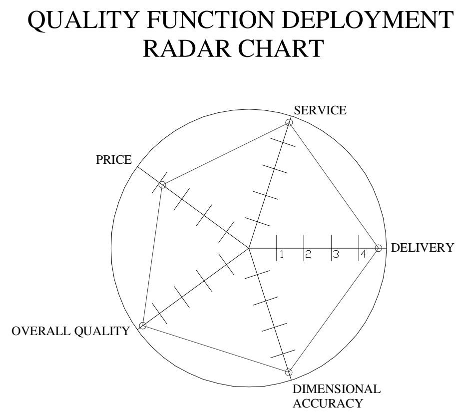

Figure 6. Radar chart displaying the results of the survey

The correlations section was deemed critical because this describes important areas that need attention when analyzing the customer requirements for individual jobs. The correlations that were important had to have a correlation of two or negative two. The rationale behind this decision—to focus on major issues and strong correlations—was that the job-shop environment is fast-paced and this study is short-term in nature. The first strong correlation was the delivery and delivery-time section. There was a strong positive correlation of two, and the design target was two; therefore, the total correlation was the correlation multiplied by the design target, which equaled four. Delivery is one aspect of a job shop that is extremely important; customers are demanding and may choose a competitor's quote over Reynolds' quote based on the delivery time and not the price. The next strong correlation existed between delivery time and service. This was a strong negative correlation of negative two. As delivery time increases the customer perception of service decreases. The correlation between cost and price was two but the design target was zero, which produced an answer of zero. This correlation was not a priority, according to the management at Reynolds. The same relationship existed between delivery time and price. All of the other relationships were seen by the management to be secondary factors, equally important but not as important as delivery and service.

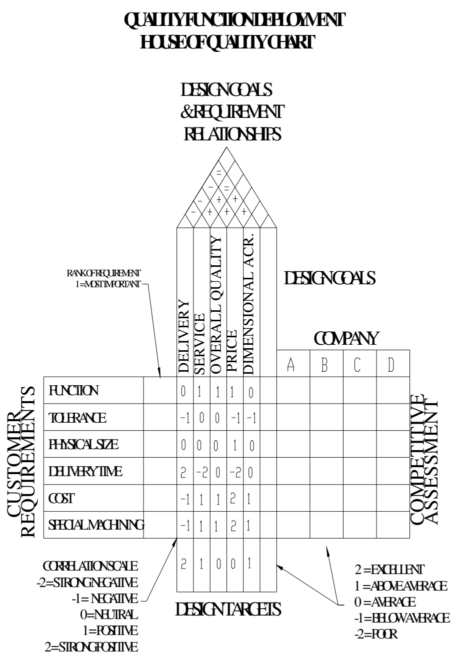

Figure 7. The House of Quality chart for organizational goals and customer requirements (this was driven by the chart to stimulate customer requirements, shown in Figure 2)

Conclusions

This research could be generalized to other similar situations but is unique to the specific company where it was performed. The methodology used for the application of QFD into the design process at Reynolds was unique in that the majority of research involving QFD was focused on large consumer-based companies and not small job-shop business-to-business companies.

The progression of the implementation of QFD at Reynolds brought up other areas that were problems, such as communication and ordering. The communication gap was reduced by the drawing documentation that conveyed important information to the manufacturing department after the design department had finished their part. The management at Reynolds saw processes that needed improvement that may not directly be influenced by QFD, but they were improvements that were needed in order to make the design department work more efficiently. One such example was the order list that was made to display commonly-ordered items with quantities to order and prices along with the supplier and contact name. This made it easier for whoever was ordering at that time to find the correct part numbers and quantities without wasting time. The quoting process was somewhat detailed, but as far as knowing the correct rates to charge—according to the type of work—was somewhat ambiguous. Thus, a quoting procedure was documented along with the best suppliers of materials for quoting purposes. This aided in finding the best sources as well as having a standardized method to follow while quoting. The purpose of this in terms of QFD was that this was a way to increase efficiency and to provide the best prices possible since, according to the survey, price was a controversial topic. The surveys aided Reynolds in discovering, on an organizational basis, where they stand with their customers.

The improvement at Reynolds came from closing the gaps in communication and understanding the customer better by knowing what is most important to them. One requirement that developed during the study was that the customers suggested that Reynolds' employees work Saturdays, because most of them are operating 24 hours per day seven days a week. The case study was successful in providing research into the implementation of QFD concepts to improve the design process, although the design time and the number of design changes were not significantly decreased. The discovery that job shops better understand their customers through direct interaction than do large consumer-based companies is a very important aspect of this case study.

References

[1] Juran, J.M. (Ed.), 1999, Juran's Quality Control Handbook, 5th ed., McGraw-Hill, New York, NY.

[2] Ternimko J., 1997, Step-by-Step QFD Customer-Driven Product Design, 2nd ed., St. Lucie Press, Boca Raton, FL.

[3] Cristiano, J.J., Liker, J.K., and White, C.C. III, 2001, "Key factors in the successful application of Quality function deployment (QFD)," *IEEE Transactions on Engineering Management*, 48, 1, 81-95.

[4] Prasad, B., 1998, "Review of QFD and related deployment techniques," *Journal of Manufacturing Systems*, 17, 3, 221-234.

[5] Sullivan, L.P., 1986, "Quality function deployment: A system to assure that customer needs drive the prod-

uct design and production process," *Quality Progress*, 19, 6, 39-50.

[6] Thomson, B.A., Badar, M.A., and Zhou, M., 2007, "Implementing QFD into a small job shop design process: a case study," IIE *Proceed. of the 2007 Industrial Engineering Research Conf.,* G. Bayraksan, W. Lin, Y. Son, and R. Wysk (eds.), 1126-1131, CD-ROM:IIE07/Research/IIE-202A.pdf, Nashville, TN, May 19-23.

[7] Bozzone, V., 2002, Speed to Market: Lean Manufacturing for Job Shops, 2nd ed., Amacom, New York, NY.

[8] QFD Institute, 2007, http://www.qfdi.org, retrieved on Jan 25, 2007.

[9] Hunt, R.A. and Xavier, F.B, 2003, "The leading edge in strategic QFD," *The Int. J. of Quality & Reliability Management*, 20, 1, 56-73.

[10] Jiang, J.-C., Shiu, M.-L., and Tu, M.-H., 2007, "Quality function deployment (QFD) technology designed for contract manufacturing," *The TQM Magazine*, 19, 4, 291-307.

[11] Shiu, M.-L., Jiang, J.-C., and Tu, M.-H., 2007, "Reconstruct QFD for integrated product and process development management," *The TQM Magazine*, 19, 5, 403-418.

[12] Lockamy, A. III, and Khurana, A., 1995, "Quality function deployment: Total quality management for new product design," *The Int. J. of Quality & Reliability Management*, 12, 6, 73-84.

[13] Bouchereau. V. & Rowlands, H., 2000, "Methods and techniques to help quality function deployment (QFD)," Benchmarking, 7, 1, 8-19.

[14] Akao, Y., 1990, Quality Function Deployment: Integrating Customer Requirements into Product Design, Productivity Press, Cambridge, MA.

[15] Hauser, J.R. and Clausing, D., 1988, "The house of quality," *Harvard Business Review*, 66, 3, 63-73.

[16] Hauser, J.R. and Katz, G.M., 1998, "Metrics: You are What You Measure!" *European Management Journal*, 16, 5, 517-528.

[17] Mazur, G., 2003, "Voice of the Customer (Define): QFD to Define Value," ASQ *Annual Quality Congress Proceedings,* USA, 57, 151-157.

[18] Conner, G., 2001, Lean Manufacturing for the Small Shop. Society of Manufacturing Engineers, Dearborn, MI.

[19] Bralla, J.G., 1999, Design for Manufacturability Handbook, 2nd ed., McGraw-Hill, New York, NY.

[20] Thomson, B.A., 2005, A case study on implementation of quality function deployment into the design process of a small job shop, MS thesis (Advisor: Dr. Badar), Indiana State University.

[21] Minium, E.W., Clarke, R.C., and Coladarci, T., 1999, Elements of Statistical Reasoning, 2nd ed., John Wiley & Sons, Inc., Hoboken, NJ.

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