QFD in the Food Processing Industry

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Abstract
QFD began in the 1960s as a new product development method to assure the quality of new products quickly and efficiently. Its first application was in a chemical process application for automobile tires. Unlike problem solving quality approaches that are applied to known problems, QFD's strength is in creating positive value and preventing negative quality before it is designed into downstream processes where it is much more expensive to correct. Unlike manufactured and assembled products, chemical and food applications require understanding of how the ingredients and recipes deliver finished products, how they scale from the laboratory to full production, what are key process indicators to control, and how packaging can affect the overall product. This paper will address some of the basics of QFD and demonstrate some of its tool set using food industry case studies.

Key Words
QFD, Quality Function Deployment, AHP, bagels

Introduction
Quality Function Deployment began forty years ago in Japan as a quality system focused on delivering products and services that satisfy customers. To efficiently deliver value to customers, it is necessary to listen to the "voice" of the customer throughout the product or service development process. From 1966, the late Dr. Shigeru Mizuno, Dr. Yoji Akao, and other quality experts in Japan developed the tools and techniques of QFD and organized them into a comprehensive system to assure quality and customer satisfaction in new products and services [Mizuno and Akao 1994, Akao 1990]. In 1983, a number of leading North American firms discovered this powerful approach and have been using it with cross-functional teams and concurrent engineering to improve their products, as well as the design and development process itself. QFD has been heralded for such benefits as promoting cross-functional teams, improving internal communications between departments, getting a better view of the competition, and translating the customer's needs into the language of the organization.

QFD for Food Producers
Unlike assembled products which can be repaired by replacing a defective part, food and chemically processed products must be produced right the first time, or scrapped. Thus, the first quality activity to engage is good process design and control. Once processes are repeatable, the next quality stage is to make products that further excite customers beyond what you and competitors are offering today. To begin, we must understand that there are different types of customer requirements to meet.

Types of Customer Requirements
To satisfy customers, we must understand how meeting their requirements affects satisfaction. There are three types of quality requirements to consider (see Figure 1) [Kano, *et. al.*, 1984].

One-dimensional quality is typically what we get by just asking customers what they want. These requirements satisfy (or dissatisfy) in proportion to their presence (or absence) in the product or service. For example, if coffee is served hot, customers are pleased. If it's cold or too hot, dissatisfaction occurs.

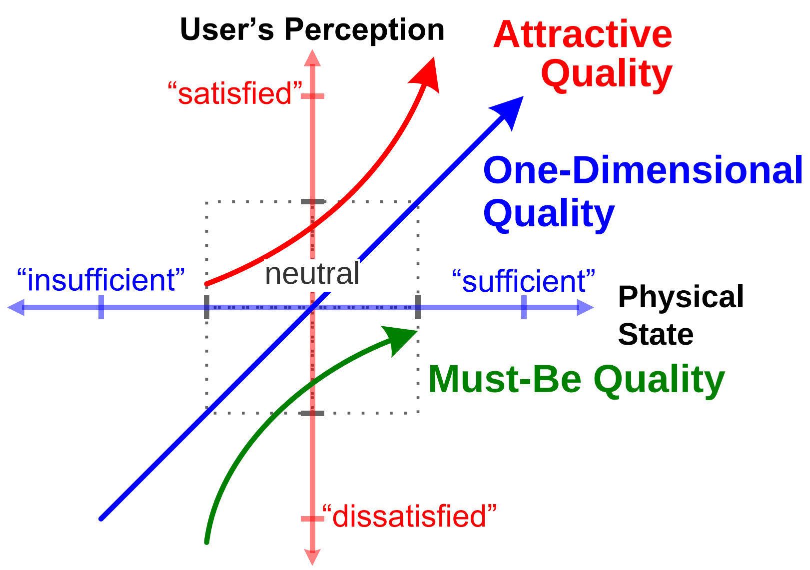

Figure 1. Kano model

Must-be quality is often so basic the customer may fail to mention them - until we fail to perform them. They are basic expectations without which the product or service may cease to be of value; their absence is *very* dissatisfying. Further, meeting these requirements often goes unnoticed by most customers. Food safety would be a good example. Food safety does not in and of itself sell a product, but a lack of it is an extreme dissatisfier. Expected requirements *must* be fulfilled.

Attractive quality is difficult to discover. They are beyond the customer's expectations. Their absence doesn't dissatisfy; their presence excites. For example, if a food specialty comes in the various varieties of the region of origin, customers are very pleased. If not, customers would hardly complain. These are the things that wow the customers and bring them back. Since customers are not apt to voice these requirements, it is the responsibility of the organization to explore customer problems and opportunities to uncover such unspoken items.

Kano's model is also dynamic in that what attracts us today must be there tomorrow. That is, once introduced, the attractive feature will soon be imitated by the competition and customers will come to expect it from everybody. An example would be the ability to have pizza delivered in thirty minutes. Once the service is begun by one company, the competitors must offer the same or better in order to retain their customers. On the other hand, expected requirements can become exciting after a real or potential failure. An example might be when the passengers applaud after a pilot safely lands the airplane in rough and stormy weather.

The Kano Model has an additional dimension regarding which customer segments the target market includes. For example, caviar and champagne that's exciting on a domestic air flight might be expected on a first class flight from New York to London. Knowing which customer segments you serve is critical to understanding their quality requirements.

Thus, eliminating problems handles must-be quality. There is little satisfaction or competitive advantage when nothing goes wrong. Conversely, great value can be gained by discovering and delivering on attractive quality ahead of the competition. QFD helps assure that must-be quality doesn't fall through the cracks and points out opportunities to build in attraction.

In summary, Kano found that the attractive quality, which are most tied to adding value, is invisible to both the customer and the provider. Further, it may change over time, technology, market segment, etc. The Japanese creators of QFD developed tools such as the Voice of Customer table [Mazur 1993] and coupled them to affinity diagrams and hierarchy diagrams to break through this dilemma.

The Host Marriott Bagel Case Study

Within the Marriott family, the Host Division was responsible for providing food services in airports, travel plazas, and other similar locations. A strategic planning effort suggested that future growth in revenue would likely come more from existing markets than from entering new ones, and that the key would be to improve product quality in order to command higher prices. This was especially true among business travelers on expense accounts who would be reimbursed for reasonable meal fares, but who balked at paying high prices for poor quality meals.

Customer Deployment

Since QFD, like most quality activities, tries to focus resources on the most important areas, it was useful to understand which customers needed to be satisfied most. The logic here was that if Host could meet or exceed the most important expectations of the most important customers, the rest would take care of itself. The generic model of customer deployment [Mazur 1993a] flows from identifying and prioritizing project success criteria to identifying and prioritizing core competencies to identifying and prioritizing customer segments. Since they were already dealing with strategic competencies, the next step was to redefine the customer deployment to fit their situation. Figure 2 is a matrix flow chart of that process and figures 3 and 4 give a portion of the details. The purpose of these matrices was to determine key customers of key unit types (terminal, unit area, etc.), that would sell the targeted baked good, that would lead to the project being deemed successful by management. Once identified, they could target their market research on these customer segments first, thus conserving research activities to the most fruitful segments. Note that QFD matrices are often cascaded where the priorities outputted from one are used as the inputs to the next level of analysis.

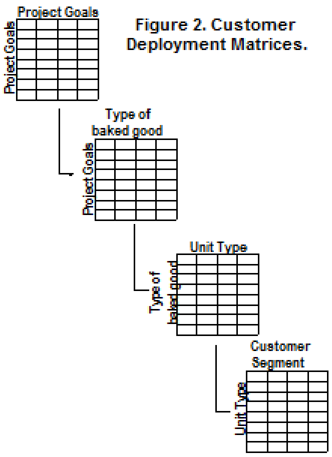

Figure 2. Customer Deployment Matrices.

Fig. 3. Prioritization of project goals.	CS	AS	LL	PI	WR	RAW SCORE	% OF TOTAL
CUSTOMER SATISFACTION (CS)	1	5	10	5	10	31.0	**40.5%**
ASSOCIATE SATISFACTION (AS)	0.2	1	5	5	10	21.2	**27.7%**
LANDLORD SATISFACTION (LL)	0.1	0.2	1	0.2	5	6.5	**8.5%**
PROFIT IMPROVEMENT (PI)	0.2	0.2	5	1	10	16.4	**21.4%**
WIN & RETAIN CONTRACTS (WR)	0.1	0.1	0.2	0.1	1	1.5	**2.0%**
TOTALS	1.60	6.50	21.20	11.30	36.00	76.60	100.0%

The first task was to clearly define how the project would be judged successful by Host's management. First, the team brainstormed and then used a relationship diagram (details omitted) to understand the drivers and "resultors" of these goals. We found that customer satisfaction drove many of the other goals and should be the primary focus of the project. Increased sales, profit improvement, landlord satisfaction, associate satisfaction and 15 other goals were identified. With an affinity diagram, they were grouped under 5 headers: customer satisfaction, associate satisfaction, landlord (airport authority) satisfaction, profit, and won and retained sales contracts. Some goals were more important than others, and so the Analytic Hierarchy Process was used to prioritize them. See Figure 3.

Prioritization in multi-criteria decision making was advanced by the research of Dr. Thomas Saaty in the 1970s at the U.S. Department of Defense and later at the Wharton School of Business at the University of Pennsylvania. Saaty found that decision makers facing a multitude of elements in a complex situation innately organized them into groups sharing common properties, and then organized those groups into higher level groups, and so on until a top element or goal was identified. This is called a hierarchy and when making informed judgments to estimate importance, preference, or likelihood, both tangible and intangible factors may be included and measured. The Analytic Hierarchy Process (AHP) was created to manage this process in a manner that captures the intuitive understanding of the participants and also yields mathematically stable results expressed in a numerical, ratio scale. A numerical, ratio scale is preferred for the following reasons.

1) Numerical priorities can be applied to later analyses to derive downstream priorities.
2) Ratio scale priorities show precisely how much more important one issue is than another. Ordinal scales only indicate rank order, but not the magnitude of importance.
3) Numerical scales can be tested for judgment inconsistency, sensitivity, and other useful properties.

AHP has been successfully applied in many government and industry decisions to clarify fuzzy and often emotional goals, and build consensus on the best ways to address them.

The next step was to augment the traditional baked goods with other potential varieties in order to identify the kinds of baked goods that might lead to customer satisfaction in an airport setting. A hierarchy of possible baked goods offerings was created (Figure 4)

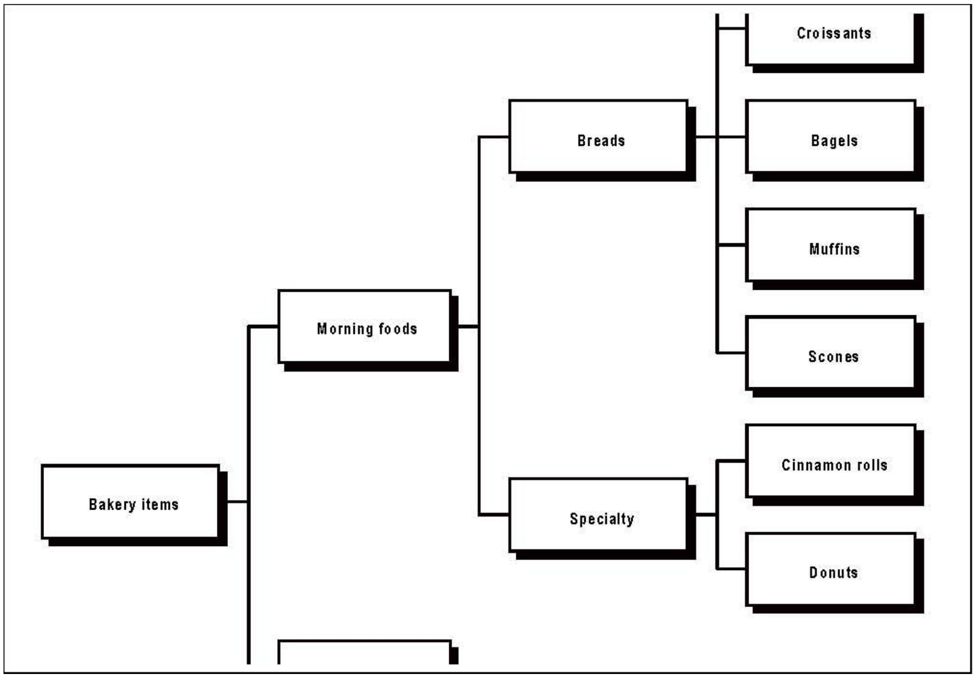

Figure 4. Hierarchy of types of baked goods (partial)

The baked goods hierarchy was prioritized in a matrix from the project goals and their priority weights (Figure 5). The analysis was to determine which baked goods would contribute most to the success of the project goals. From this, bagels were selected. QFD matrices are used to transfer priority from one data set, here project goals in the rows, to another set, here baked goods in the columns, by multiplying the row priorities times a weighting factor indicated by the symbols in the connecting cells, and adding these column by column.

	Croissants	Bagels	Muffins	Danish	Priorities
Customer Satisfaction	○	◎	◎	△	40.5
Associate Satisfaction	△	◎	○	△	27.7
Landlord Satisfaction		△	△		8.5
Profit Improvement	△	◎	○	△	21.4
Win and Retain Contracts		△	△		2.0
Absolute Weights	170.6	814.9	522.3	89.6	
Product Type Weights	**10.7**	**51.0**	**33.0**	**5.6**	

Figure 5. Project goals to product types matrix

The next step was to determine the type of retail unit Host would sell these in. A matrix was created with the highest priority baked goods and the type of unit (Figure 6). The unit types included full service restaurant, concourse kiosk with large display cases, kiosks with small display cases, and branded outlets. From this matrix we learned the type of sales unit which would be most successful at selling bagels - the concourse kiosk with large display cases.

	Full Service	Large Display	Small Display	Brands	Product Type Weights
Croissants	△	◎	◎	○	10.7
Bagels	△	◎	○	△	51.0
Muffins	△	◎	○	△	33.0

Figure 6. Product types to retail unit type matrix

The next phase was to identify customer types based upon use characteristics such as time of day, purpose of coming to airport, etc. This was a change from the usual market research that delivers demographic characteristics, such as income, education, etc. A matrix (Figure 7) was made to prioritize with the unit type based upon what type of customer was most likely to eat at a concourse kiosk. The highest priority customer segment turned out to be core business travelers, with women traveling in the morning on business a surprisingly strong sub-segment. The team decided to look at both men and women. The next step was to go to the airport and determine the needs of these key customers.

	Core Business	Meeters/ Greeters	Airport Workers	Unit Type Weights
Full Service	△	△	△	5.7
Large Display	◎	△	○	49.0
Small Display	◎	△	○	34.2
Brands	○	△	○	11.1

Figure 7. Unit types to customer segments matrix

Voice of Customer Deployment

One unique approach to QFD to better understand customers is to visit them where they work or live – in this case, the airport kiosks. This is called going to *"gemba"* referring to the Japanese quality term meaning where the truth can be discovered. At the gemba, the spoken words and observed actions of the customer were recorded in the Gemba Visit table and Customer Voice table (details omitted), which record usage data, such as time of day, whether meal or snack, etc. and sort the voices into benefits vs. features, respectively. The benefits, called customer needs in QFD, included items such as "healthy choice," "taste I like," "appealing choice," etc.

A survey was conducted of bagel eaters at the gemba and about 50 responses were received. Demographics were about 40% men to 60% women, about evenly split between Phoenix Arizona residents (where the pilot study was being conducted) and those who were not, and were about twice as many pleasure travelers as business travelers. They were asked to prioritize these needs so that we would know which they valued the most. AHP can be used here to get more accurate priorities. The objective then became to exceed the competition in those benefits which were most important to the customer. A portion of the survey results are shown in the figure 8.

Figure 8. Prioritization of customer needs with AHP.

Tertiary Level Needs	1.1.1	1.1.2	1.1.3	1.1.4	normalized columns				row total	**RANC** row avg.	Global Wt.
1.1.1 Healthy choice	1	1/5	3	4	0.152	0.135	0.293	0.222	0.802	0.201	**11.5%**
1.1.2 Taste I like	5	1	6	9	0.759	0.677	0.585	0.500	2.522	0.630	**36.1%**
1.1.3 Appealing choice	1/3	1/6	1	4	0.051	0.113	0.098	0.222	0.483	0.121	**6.9%**
1.1.4 Choose quickly	1/4	1/9	1/4	1	0.038	0.075	0.024	0.056	0.193	0.048	**2.8%**
	6.583	1.478	10.250	18.000	1.000	1.000	1.000	1.000	4.000	1.000	**57.3%**

Inconsistency Ratio = 0.09

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House of Quality

The next phase was to translate the customer needs into product measurements and performance targets that would help us design the new bagel right the first time. In traditional QFD, this is often done with a special matrix called the House of Quality. In modern QFD, a more efficient tool called the Maximum Value table is used first. The analysis required a study of the service requirements, bagel requirements, and a special toaster requirement. The service analysis done first suggested that if we purchased par-baked bagels, stored them frozen in each kiosk, and then finished baked them to specified inventory levels, we could offer customers both large variety and freshness. A bagel vendor needed to be found that was willing to adapt their product to the baking needs of untrained bakers baking in small batches in an airport environment. The House of Quality (figure 9) brings together on one sheet of paper the customer needs, preferences, and choice data from the market survey, the company's response to those needs in terms of produce measures and performance targets, and yields a prioritized set of areas the finished product needs to address first. These are then deployed into frozen dough qualities which would then be deployed into a recipe and production parameters. For ease of data entry in a spreadsheet, the matrix relationship symbols shown in the above matrices have been replaced with their numerical equivalent.

Customer Needs \ Finished Bagel Characteristics	Adjusted Customer Weight (from QPT)	Texture	Volume	Appearance	Fermentation By-Products
1.1.1 Healthy choice	**19.9%**				**0.13**
1.1.2 Taste I like	**51.7%**	**0.26**		**0.07**	**0.13**
1.1.3 Appealing choice	**17.1%**	**0.13**	**0.13**	**0.50**	
1.1.4 Choose quickly	**11.4%**			**0.07**	
Absolute Weight		**0.16**	**0.02**	**0.13**	**0.10**
Finished Bagel Char Weight		**38.8%**	**5.7%**	**31.7%**	**23.7%**

Figure 9. House of Quality for finished bagel (partial).

Batch Deployment

The finished bagel characteristics were then deployed to frozen par-baked dough characteristics that were desired from the bagel vendor. A matrix was used to transfer finished bagel characteristics priorities into frozen dough characteristics. (Figure 10) As in the above matrices, note that the finished bagel characteristics and weights that were in the House of Quality columns have been rotated to the input rows of the batch deployment matrix, thus preserving the customer priorities even as the analysis drills down to further and further detail.

Frozen Par-baked Dough Char-acteristics / Bagel Characteristics	Bagel Weights (%)	Moisture Retention	Dough Strength	Freeze-Thaw Stability	Crumb Structure	Gas Retention
Texture	38.8%	0.50	0.50	0.26	0.50	
Volume	5.7%	0.50	0.26	0.26		0.50
Appearance	31.7%		0.13		0.13	0.13
Fermentation By-Products	23.7%	0.13		0.13		
Absolute Weight		0.26	0.25	0.15	0.24	0.07
Dough Char Weight		26.5%	26.2%	15.3%	24.7%	7.4%

Figure 10. Finished bagel – frozen par-baked dough characteristics matrix (partial).

Recipe Deployment

The frozen par-baked dough characteristics were then deployed into recipe adaptations to meet the requirements of small batch baking by unskilled bakers in a high-vibration airport environment. The recipe deployment includes both ingredient specifications (Figure 11) and process parameters (Figure 12).

Ingredients / Dough Characteristics	Dough Char Weights (%)	Flour	Sweetener	Yeast	Oxidants	Surfactants	Enzymes	Water
Moisture Retention	26.5%	0.13	0.21	0.07		0.13		0.26
Dough Strength	26.2%	0.50		0.13	0.26		0.26	0.26
Freeze-Thaw Stability	15.3%		0.13	0.26	0.26	0.26		0.13
Crumb Structure	24.7%	0.13	0.13	0.26		0.07	0.21	
Gas Retention	7.4%	0.13		0.50		0.07	0.13	
Absolute Weight		0.21	0.11	0.19	0.11	0.10	0.13	0.16
Ingredient Weight		24.8%	12.9%	22.9%	12.7%	11.4%	15.3%	18.6%
Specifications		12.5 protein	high fructose corn syrup	liquid cream, 2x	Ascorbic Acid, ADA<45ppm	Sodium Stearoyl lactylate	fungal alpha-amylase	

Figure 11. Dough characteristics - ingredients matrix

Manufacturing Process / Dough Characteristics	Dough Char Weights (%)	Dough Mix Temp	Water Temp	Ingredients adding	Scale	Shape	Intermediate Proof	Boil	Partial Bake	Freeze	Package
Moisture Retention	26.5%		0.50					0.26		0.50	0.26
Dough Strength	26.2%			0.26					0.26		
Freeze-Thaw Stability	15.3%	0.50	0.50	0.26	0.26	0.26	0.26		0.26	0.26	
Crumb Structure	24.7%							0.13	0.13		0.13
Gas Retention	7.4%	0.50								0.13	
Absolute Weight		0.11	0.21	0.11	0.04	0.04	0.04	0.10	0.14	0.18	0.10
Mfg Process Weight		10.6%	19.5%	10.0%	3.7%	3.7%	3.7%	9.5%	13.1%	16.9%	9.5%
Specifications		<70°F	ninimize	ht-dough	<70°F	<70°F	<70°F	minutes	tes (80%)	reeze to oreage - 10°F	ture and n barrier

Figure 12. Dough characteristics - process matrix

Process Quality Control

Key processes requiring tighter control were then documented for control parameters, inspection frequency and methods, documentation, etc. as shown in figure 13. Additional quality activities for plant, receiving inspection, packaging, etc. priorities were also noted.

[T] Critical to taste
[S] Critical to safety
Department:
Prepared by: JT 3/92
Checked by: RZ 3/92
Approved by: GM 4/92
Product Name: Par-baked frozen bagels for Host

Process Step	Ingred-ients	Process Control				Step No.	Equip., mat'l	QC item	Spec. Value	QC Check				Reason for control
		Condi-tions	Frequen-cy	Method	Standard					Freq	Method	Chk by	Doc	
Mixing	flour	12.50%	1/batch	bag label	61-2	2	Stainless	Mixing temp	< 70°F	1/hr.	gage	Foreman	x-R	prevent yeast ferment
Scaling	dough	4oz.	each	form		3	Tray	temp	< 70°F	1/tray	scale	Operatior	x-R	assure weight

Figure 13. Production process quality control sheet (partial).

Finish Baking Deployment

The final task was to examine the on-site baking process in each airport kiosk to protect the end product from quality problems in the final steps. A matrix of the finished bagel to the on-site baking process is shown in figure 14.

On-site Baker Process / Bagel Characteristics	Bagel Char Weights (%)	Storage Temp	Shelf Life	Retard (thaw) Time	Proof Condiditons	Baking Temp	Baking Time
Texture	38.8%		0.26	0.26	0.13	0.50	0.50
Volume	5.7%	0.50	0.26	0.26			
Appearance	31.7%	0.13		0.26		0.50	0.50
Fermentation By-Products	23.7%	0.26		0.13	0.13		
Absolute Weight		0.13	0.12	0.23	0.08	0.35	0.35
Baker Process Weight		10.4%	9.1%	18.1%	6.6%	27.9%	27.9%
Specifications		Constant -10°F	max. 26 weeks	33-40°F, 4 hours	unnecessary	350°F in convection oven	6 minutes

Figure 14. Finished bagel characteristics - on-site baking process matrix.

Results
After the service and product changes were implemented, sales performance and customer feedback were monitored to gauge the success of the project. Some of the results are shown in figures 15 and 16.

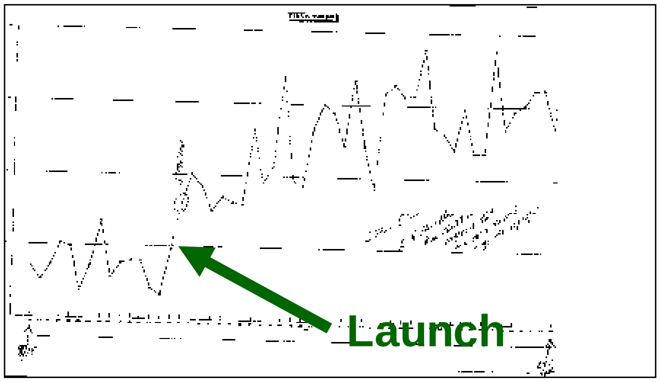

Figure 15. Improvement in sales levels after launching new product.

Figure 16. Improvement in taste compared to other bagel stores.

Conclusion
This analysis began by formulating and prioritizing the business goals with customer satisfaction, associate satisfaction, and profit improvement accounting for 90% of the success factors for the project. The results shown above clearly indicate the sales increase (profit margins were increased but are confidential) and increased customer satisfaction with taste. Other metrics related to the service part of the study also showed increases.

The steps to connect the success factors and the actual results included customer deployment, voice of customer deployment, House of Quality, batch deployment, recipe deployment, process quality control, and finish baking deployment. Customer deployment helped the QFD team focus on business travelers eating bagels purchased at large display airport concourse kiosks. Voice of customer deployment helped prioritize spoken and unspoken customer needs including "taste I like." The House of Quality prioritized the needs into finished bagel characteristics such as texture and appearance. The batch deployment prioritized the finished bagel characteristics into frozen par-baked dough characteristics such as moisture retention, dough strength, and crumb structure. The dough characteristics were then deployed into key ingredients (flour and yeast which were optimized using a design of experiment not shown) and manufacturing process parameters (water temperature and freeze temperature). Process quality control sheets were then established to train operators and monitor the key processes. Finally, the finished baking process in the airport kiosk was examined and it was determined that baking time and temperature were key to successfully producing the bagels, so control devices were introduced here, as well.

The application of QFD to a food or chemical process can be quite different than to a mechanical or assembled product, and the resulting deployments must be tailored even further to express the peculiarities of each company and its management structure. Thus, even another food producer might do its QFD differently. Determining the best QFD process, whether to use Blitz QFD® or the traditional QFD matrices shown here, and other considerations should not be ignored as is too often the case. Those seeking to apply QFD to their products should seek out the guidance of a skilled QFD person, such as the QFD Master Black Belts® certified by the QFD Institute.

About the author

Glenn H. Mazur has been active in QFD since its inception in North America, and has worked extensively with the founders of QFD on their teaching and consulting visits from Japan. He is a leader in the application of QFD to service industries and consumer products, conducts advanced QFD research, and is the Conference Chair for the annual North American Symposium on Quality Function Deployment. Glenn is the Executive Director of the QFD Institute and International Council for QFD, Adjunct Lecturer on TQM at the University of Michigan College of Engineering (ret.), President of Japan Business Consultants Ltd., and is a senior member of the American Society for Quality (ASQ), and the Japanese Society for Quality Control (JSQC). He is a certified QFD Red Belt® (highest level), one of two in North America. He is a certified QFD-Architekt #A21907 by QFD Institut Deutschland. Additional papers and related topics may be found by linking on the Internet through the following home page: www.mazur.net

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