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Applications of statistical and related methods to new technology and product development process —

Part 3: Quantitative approaches for the acquisition of voice of customer and voice of stakeholder

Application des méthodes statistiques et des méthodes liées aux nouvelles technologies et de développement de produit —

Partie 3: Acquisition quantitative du retour client (voice of customer) ou du retour des parties prenantes (voice of stakholders)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by ISO/TC 69, *Applications of statistical methods*, Subcommittee SC 8, *Application of statistical and related methodology for new technology and product development*.

A list of all parts in the ISO 16355 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

Quality Function Deployment (QFD) is a method to assure customer or stakeholder satisfaction and value with new and existing products by designing in, from different levels and different perspectives, the requirements that are most important to the customer or stakeholder. These requirements can be well understood through the use of quantitative and non-quantitative tools and methods to improve confidence of the design and development phases that they are working on the right things. In addition to satisfaction with the product, QFD improves the process by which new products are developed.

Reported results of using QFD include improved customer satisfaction with products at time of launch, improved cross-functional communication, systematic and traceable design decisions, efficient use of resources, reduced rework, reduced time-to-market, lower lifecycle cost, and improved reputation of the organization among its customers or stakeholders.

This document demonstrates the dynamic nature of a customer-driven approach. Since its inception in 1966, QFD has broadened and deepened its methods and tools to respond to the changing business conditions of QFD users, their management, their customers, and their products. Those who have used older QFD models find these improvements make QFD easier and faster to use. The methods and tools shown and referenced in the standard represent decades of improvements to QFD; the list is neither exhaustive nor exclusive. Users can consider the applicable methods and tools as suggestions, not requirements.

This document is descriptive and discusses current best practice, it is not prescriptive by requiring specific tools and methods.

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Applications of statistical and related methods to new technology and product development process —

Part 3: Quantitative approaches for the acquisition of voice of customer and voice of stakeholder

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1 Scope

This document describes quantitative approaches for acquisition of the voice of customer (VOC) and voice of stakeholder (VOS) and its purpose, and provides recommendations on the use of the applicable tools and methods. It is not a management system standard.

NOTE It does not provide requirements or guidelines for organizations to develop and systematically manage their policies, processes, and procedures in order to achieve specific objectives.

Users of this document include all organization functions necessary to assure customer satisfaction, including business planning, marketing, sales, research and development (R&D), engineering, information technology (IT), manufacturing, procurement, quality, production, service, packaging and logistics, support, testing, regulatory, and other phases in hardware, software, service, and system organizations.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10004:2018, *Quality management — Customer satisfaction — Guidelines for monitoring and measuring*

ISO 3534-1:2006, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

ISO 3534-4:2014, *Statistics — Vocabulary and symbols — Part 4: Survey sampling*

ISO 16355-1:2015, *Application of statistical and related methods to new technology and product development process — Part 1: General principles and perspectives of Quality Function Deployment (QFD)*

ISO 20252:2012, *Market, opinion and social research — Vocabulary and service requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 3534-1, ISO 3534-4, ISO 16355-1, ISO 10004 and ISO 20252 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

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4 Basic concepts of QFD

The basic concepts of QFD are described in ISO 16355 1:2015, Clause 4.

5 Integration of quantitative voice of customer (VOC) and voice of stakeholder (VOS) acquisition with customer research methods

Integration of quantitative voice of customer (VOC) and voice of stakeholder (VOS) acquisition with customer research methods is described in ISO 16355-1:2015, 8.2 and ISO 16355-2:2017, Clause 5.

6 Types of QFD projects

QFD projects encompass new developments, as well as generational improvements to existing products. The types of QFD projects are described in ISO 16355-1:2015, Clause 6 and ISO 16355-2:2017, Clause 6 Notes.

7 QFD team membership

7.1 QFD uses cross-functional teams

Cross-functional teams are described in ISO 16355-1:2015, 7.1.

7.2 Core team membership

Core team membership is described in ISO 16355-1:2015, 7.2.

7.3 Subject matter experts

Subject matter experts' involvement is described in ISO 16355-1:2015, 7.3.

7.4 QFD team leadership

QFD team leadership is described in ISO 16355-1:2015, 7.4.

NOTE It is common for quantitative VOC and VOS acquisition to be led by market researchers. This can be an internal department or outsourced to a third-party organization.

8 Types of information

8.1 General

Quantitative methods and tools are used in QFD to understand, structure, prioritize, and analyze voice of customer and stakeholder. These are summarized in Table 1.

8.2 Market strategy and trends

8.2.1 General

Quantitative information is useful in setting strategies and projects for new product development. It is the basis for both the objective and subjective decision making described in ISO 16355-2:2017, 9.1.2.

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8.2.2 Analytic network process (ANP)

The ANP is used to prioritize alternative plans for achieving strategic objectives that require input from multiple stakeholders[1]. ANP is described in 9.1.

8.2.3 Porter 5 force competitive analysis

This is used in strategic planning to give a high level view of future market opportunities and threats. Its use in QFD is described in ISO 16355-2:2017, 9.1.2.3.

8.2.4 Market position analysis

This is used to show current and trending changes in markets. Its use in QFD is described in 9.8.

8.2.5 Project selection

Quantification is used to identify both objective and subjective criteria that can be used to synthesize a prioritized project portfolio. The analytic hierarchy process (AHP) is used throughout QFD for this purpose. Its use in QFD is described in ISO 16355-2:2017, 9.1.2.8.

8.3 Market segments

8.3.1 General

Quantitative information is useful in identifying potential market segments and applications during new product development which is described in ISO 16355-2:2017, 9.2.2.

8.3.2 Demographic market segmentation

Market segments can be analyzed according to demographic attributes using cross tabulations. Its use in QFD is described in 9.9.

8.3.3 Attitudinal and cultural dimensions

Demographics, attitudes, and culture can affect how customers respond to surveys and visits. Quantification of these factors and its use in QFD is described in 9.5.

8.3.4 New Kano model studies

Using knowledgeable consumers to respond to Kano model satisfaction surveys, the new Kano model can be used to reveal hidden market segments. Its use in QFD is described in ISO 16355-5:2017, 10.3.4.4.8.1.

8.3.5 Repertory grid technique

In addition to the obvious physical characteristics of a product, for example shape or color, there can also be unconsciously perceived customer-specific characteristics. The repertory grid technique helps customers and stakeholders reveal their personal constructs by organizing and scoring product characteristics. Its use in QFD is described in 9.15.

8.4 Competitive space

8.4.1 General

In new product development, it is important to understand the alternative choices that customers can make. This can include both similar products as well as new technologies. The following tools are useful in ISO 16355-2:2017 and ISO 16355-4.

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8.4.2 Benchmarking

Benchmarking is used to capture customer perceptions about current and competitive products, as well as to plan future product placement in QFD. Customer perception benchmarking is used in the quality planning table described in ISO 16355-4:2017, 12.2.

8.4.3 Market position analysis

Market position analysis is used to understand how competing products are perceived by customers. Its use in QFD is described in 9.8.

8.4.4 Multidimensional scaling (MDS)

MDS is used to graphically display visual maps of competitive market space and opportunities. Its use in QFD is described in 9.10.

8.4.5 Repertory grid technique

Repertory grid technique is used to capture customer perceptions regarding competing products. Its use in QFD is described in 9.15.

8.5 Customer and stakeholder applications

8.5.1 Frequency of use or application

How often a customer uses a product for a certain problem or opportunity can influence design choices. Cross tabulations can be used to gather and analyze this information. Its use in QFD is described in 9.9.

8.5.2 Robust parameter design

Robust parameter design can incorporate the impact of customer usage and application as well as environmental influences in order to make the product more robust to these factors. Its use in QFD is described in ISO/TS 16355-6 and ISO 16336.

8.6 Customer needs

8.6.1 Functional needs using text analytics and text mining

Text analytics of big data is used to augment interview- and observation-derived customer needs, as described in 9.16. Customer needs are defined in ISO 16355-1:2015, 3.3 and ISO 16355-4:2017, 9.1.3.3. The use of AHP to prioritize them is described in ISO 16355-4:2017, 11.2. The house of quality is described in ISO 16355-5:2017, 9.3.6.

8.6.2 Emotional or attractive needs using kansei engineering

In QFD, customer needs are described as the benefit to the customer of their problem solved, their opportunity enabled, or their image (self or to others) enhanced. Problem solved and opportunity enabled are functional needs as described in 8.6.1. Image enhanced to self or to others are addressed using kansei engineering. Kansei engineering uses quantitative techniques such as the semantic differential, factor analysis, and multivariate analysis to explain what components at what performance level drive design elements that lead targeted customers to experience specific emotions. This is explained in ISO/TR 16355-8:2017, Clause 8. For category-type variables, the quantification methods can be used, as described in 9.13.

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8.7 Prioritization

8.7.1 General

Prioritization is used throughout QFD to focus the efforts of the design team. Modern QFD uses the analytic hierarchy process (AHP) in voice of customer and stakeholder analysis to structure and prioritize customer needs.

8.7.2 Analytic hierarchy process (AHP)

Prioritize business and project goals as well as prioritize market segments using AHP. (ISO 16355-2:2017, 9.1.2.8 and 9.1.3). Prioritize customer needs using AHP. (ISO 16355-4:2017, 11.2)

8.7.3 L-matrices

Structure and prioritize customer segments using L-matrices and AHP. (ISO 16355-2:2017, 9.2.3)

8.7.4 Cluster analysis

Structure customer needs using cluster analysis (9.4) instead of affinity diagram and hierarchy diagram. (ISO 16355-4:2017, 10.2 and 10.3)

8.7.5 Analytic network process (ANP)

Prioritize customer needs using the analytic network process (ANP) (9.1).

8.7.6 Benchmarking

Benchmark customer perceptions of current and competitive products (ISO 16355-4:2017, 12.2).

8.8 Product requirements, feature sets, concept options

8.8.1 Conjoint analysis

Conjoint analysis is used to determine what combination of product attributes and performance levels are most preferred by customers. Its use in QFD is described in 9.3.

8.8.2 Customer needs — Functional requirements matrix (house of quality)

The house of quality is used to transfer prioritized customer needs into prioritized functional requirements in QFD. Its use in QFD is described in ISO 16355-5:2017, 9.3.6.

8.8.3 Quantification method III

This variation on correspondence analysis helps uncover hidden use cases and appropriate concepts to address them. Its use in QFD is described in 9.13.2.

8.8.4 Regression analysis

Regression analysis is used to predict the effects of product performance on customer evaluations. Its use in QFD is described in 9.14.

8.8.5 Repertory grid technique

Repertory grid technique is used to what product features are desired by customers. Its use in QFD is described in 9.15.

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8.8.6 Text analytics and text mining

Text analytics of big data helps extract product features that are referenced frequently in online reviews. Its use in QFD is described in 9.16.

8.9 Distribution, logistics and inventory, sales channels

New Lanchester strategy can be used to take competitive advantage of distribution and sales channels. Its use in QFD is described in ISO 16355-2:2017, 9.1.2.6.

8.10 Customer satisfaction surveys and preference benchmarking

8.10.1 Customer satisfaction surveys

Customer satisfaction surveys are described in ISO 10004. Sample survey development guidance is described in Annex A. These can be used to produce customer satisfaction surveys based on sample survey methods.

8.10.2 Factor analysis and covariance structure analysis

Customer satisfaction and dissatisfaction surveys can be analyzed to help developers prioritize which product attributes and functional requirements are strongly associated with customer excitement or basic expectations. Its use in QFD is described in 9.6.

8.10.3 Fuzzy set theory

Customer scoring on a linear satisfaction scale is difficult when the scores are not crisp. Fuzzy set theory can be used to improve the process. Its use in QFD is described in 9.6.

8.10.4 Net promoter score (NPS)

Net promoter score is used to measure customer loyalty in terms of likelihood of recommending a product to others. Its use in QFD is described in 9.11.

8.10.5 Neural networks and artificial intelligence

Neural networks are computer models that use surveys to create and test a hypothesis of customer satisfaction and preferences. Its use in QFD is described in 9.12 and 9.2.

8.10.6 Regression analysis

Regression analysis is used to predict the effects of product performance on customer evaluations of current, competitive, and proposed products. Its use in QFD is described in 9.14.

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Table 1 — Quantitative voice of customer tools used in QFD

New product development phase	Method or tool	Detailed information
8.2 Market strategy and trends	Analytic network process (ANP)	9.1
	Porter 5 force competitive analysis	ISO 16355-2:2017, 9.1.2.3
	Market position analysis	9.8
	Project selection	ISO 16355-2:2017, 9.1.2.8

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Table 1 *(continued)*

New product development phase	Method or tool	Detailed information
8.3 Market segments	Demographics using cross tabulation	9.9
	Attitudinal and cultural dimensions	9.5
	New Kano model	ISO 16355-5:2017, 10.3.4.4.8.1
	Repertory grid technique	9.15
8.4 Competitive space	Benchmarking	ISO 16355-4:2017, 12.2
	Market position analysis	9.8
	Multidimensional scaling (MDS)	9.10
	New Lanchester strategy	ISO 16355-2:2017, 9.1.2.6
	Repertory grid technique	9.15
8.5 Customer and stakeholder applications	Frequency of use or application	9.9
	Robust parameter design	ISO/TS 16355-6, ISO 16336, ISO 16337
8.6 Customer needs	Functional needs using text analytics and text mining	9.16
	Emotional or attractive needs using kansei engineering	ISO/TR 16355-8:2017, Clause 8
8.7 Prioritization	Analytic hierarchy process (AHP)	ISO 16355-2:2017, 9.1.2.8 and 9.1.3
	L-matrices	ISO 16355-2:2017, 9.2.3
	Cluster analysis	9.4
	Analytic network process (ANP)	9.1
	Benchmarking	ISO 16355-4:2017, 12.2
8.8 Product requirements, feature sets, concept options	Conjoint analysis	9.3
	Fuzzy multiple-objective decision models for FMEA	9.7.6
	House of quality	ISO 16355-5:2017, 9.3.6
	Quantification method III and factor analysis	9.13.2
	Regression analysis	9.14
	Repertory grid technique	9.15
	Text analytics and text mining	9.16
8.9 Distribution, logistics and inventory, sales channels	New Lanchester strategy	ISO 16355-2:2017, 9.1.2.6
8.10 Customer satisfaction surveys and preference benchmarking	Customer satisfaction surveys	ISO 10004 and Annex A
	Factor analysis with covariance structure analysis	9.6
	Fuzzy set theory	9.7
	Net promoter score (NPS)	9.11
	Neural networks/artificial intelligence	9.12, 9.2
	Regression analysis	9.14

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9 Tools for quantitative VOC and VOS acquisition and analysis

9.1 Analytic network process (ANP)

9.1.1 General

The analytic network process (ANP) is used for multi criteria decision making when there are dependencies among the criteria (a network), unlike the AHP which assumes independence. Judgments in ANP represent the influence of one element over another in relationship to a third element in the network. This creates a supermatrix of prioritized clusters of elements[2].

ANP is useful when multiple, interrelated customers and stakeholders have needs which interact, such that the fulfilment of one need of one customer might positively or negatively interact with the need of another customer. If the customer value chain is linear or customers are independent, then the analytic hierarchy process (AHP) is used to prioritize customers as described in ISO 16355-2:2017, 9.2.3 and their needs as described in ISO 16355-4:2017, 11.2.

NOTE Hierarchical leveling using the affinity diagram and hierarchy diagram as described in ISO 16355-4:2017 10.2 and 10.3 respectively, becomes less important.

9.1.2 Building and analyzing the network

The following steps are used when ANP is used with QFD.

1) modeling and structuring of criteria and relationships;

2) pairwise comparisons of sub-matrices of lower level elements with respect to a third higher level element;

3) supermatrix of sub-matrices to address interdependencies in the network;

4) calculation of steady-state values of supermatrix by raising to n^{th} power, to use as priorities in maximum value table (ISO 16355-5:2017, 9.2) or house of quality (ISO 16355-5:2017, 9.3.6).

EXAMPLE Students and faculty at a university want to strengthen the curriculum (functional requirements) to improve student skills (customer needs). A model of higher level and lower level skills is shown in Table 2. A steady state supermatrix is constructed from sub-matrices and the priorities calculated (Table 3) for use in a house of quality of subjects to be taught in the university (Table 4)[3].

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Table 2 — Student skill set (partial)

Higher level	Lower level
Personal development (PD)	Make effective presentations
	Learn when new skills are needed
	Written and verbal reporting
Decision making and modeling (DM)	Model problems and design solution
	Use concepts, model, and tools
	Project management
	Use decision making process

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Table 3 — ANP Steady state super matrix (partial)

		Personal development			Decision making			
Higher level	**Lower level**	**PD1**	**PD2**	**PD3**	**DM1**	**DM2**	**DM3**	**DM4**
Personal development (PD)	1. Make effective presentations	0	0	0	0	0	0	0
	2. Learn when new skills are needed	0	0	0	0	0	0	0
	3. Written and verbal reporting	0	0	0	0	0	0	0
Decision making and modeling (DM)	1. Model problems and design solution	0,282 5	0,282 5	0,282 5	0,282 5	0,282 5	0,282 5	0,282 5
	2. Use concepts, model, and tools	0,345 6	0,345 6	0,345 6	0,345 6	0,345 6	0,345 6	0,345 6
	3. Project management	0,134 4	0,134 4	0,134 4	0,134 4	0,134 4	0,134 4	0,134 4
	4. Use decision making process	0,237 4	0,237 4	0,237 4	0,237 4	0,237 4	0,237 4	0,237 4

Table 4 — House of quality for university curriculum (partial)

			Information technology		Calculus	
Primary needs	**Secondary needs**	**ANP weight**	**Computer hardware**	**Office suite software**	**Relations between mathematics, business, and economics**	**Mathematical models for real life problems**
Decision making and modeling (DM)	Model problems and design solution	0,282 5	0,069	0,267	0,267	0,069
	Use concepts, model, and tools	0,345 6	0,267	0,267	0,267	0,000
	Project management	0,134 4	0,069	0,267	0,000	0,267
	Use decision making process	0,237 4	0,000	0,000	0,000	0,000

9.2 Artificial intelligence (AI)

The design of complex internet of things (IoT) systems can be improved by using artificial intelligence (AI) to accelerate the capture and analysis of both customer and stakeholder needs. Four developments in machine learning that can give significant support towards the QFD approach in IoT design are[4] the following.

a) Neural networks (NN). Customer needs, engineering characteristics and engineering solutions are represented as neurons. Each neuron represents a node (e.g. engineering solution is a node) and the link between neurons represents a relationship (e.g. there are relationships between engineering characteristics and customer needs). Using the NN model in QFD, the output customer satisfaction would be attained using the input parameter, engineering solutions. NN is described in 9.12.

b) Hierarchical temporal memory (HTM). This is a machine learning algorithm that can be designed to learn in an unsupervised manner to use previous knowledge to make future predictions. A cognitive model for QFD is proposed to:

1) identify customer needs;

2) prioritize customer needs;

3) prioritize solution characteristics;

4) input priorities into an AI model;

5) AI model;

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6) production control attributes for industry 4.0 application of IoT.

c) Reinforcement learning. The algorithm itself learns what needs to be done to optimize speed and quality to ensure customer satisfaction and business success.

d) Cognitive AI exploiting natural language and big data analysis. Based on AI systems, cognitive AI uses neural networks and reinforcement-learning to analyze very large amounts of data generated from business and social networking systems. This has the ability to filter and analyze big data to identify underlying trends for understanding customer and stakeholder segmentation, customer language, and behavior.

9.3 Conjoint analysis

9.3.1 General

Conjoint analysis is used to ask customers to consider jointly various product attributes in terms of their relative importance and the utility they assign to the performance levels of those attributes. A conjoint analysis helps new product developers

a) understand the importance of product attributes in the customer purchase decision;

b) estimate market share with different levels of product attributes;

c) determine the product configuration with the most preferred levels of important product attributes;

d) segment the market based on similar preferences for the levels of product attributes.

9.3.2 Types of conjoint analyses used with QFD

9.3.2.1 Trade-off conjoint analysis

Advantages of trade-off conjoint analysis are that it is easy for customers to respond to the survey and a large number of attributes can be examined. Disadvantages include that it is difficult to display concepts pictorially, interactions are hard to measure, and there can be a large number of response matrices.

9.3.2.2 Paired comparison conjoint analysis

The advantage of paired comparison conjoint analysis is that it is easy for customers to respond. Disadvantages are that with a large number of attributes, the number of comparisons grows quickly. When respondents become indifferent to the presented pairs, the presentation of choices can be stopped.

9.3.2.3 Full -profile conjoint analysis

Advantages of full-profile conjoint analysis are more realistic choices can be presented, pictorial representation can be used, and there is greater flexibility in what can be measured. Disadvantages are that information overload is possible, product attributes are limited to about 6 - 8, and it is expensive and time consuming to field a survey.

9.3.2.4 Adaptive conjoint analysis

Adaptive conjoint analysis has each respondent rank their preferred performance level for each product attribute. The performance levels are bounded with the poorest acceptable level and the highest desired level. A questionnaire is constructed with pictorial representations and respondents are asked to trade-off between 2 - 9 partial profiles presented two at a time by rating the likelihood of purchasing on a 1 - 100 scale. Advantages are that if the results are computed during the survey, the respondent remains interested, and many attributes can be tested.

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9.3.3 Building the conjoint analysis survey

1) Formulate questions for interviews.

2) Conduct the interviews.

3) Formulate the questionnaire.

4) Determine product attributes and concept designs to be tested.

NOTE 1 Attributes can be limited in number and meaningful to the customers. The number of levels and the difference between them are the same for all attributes. To survey all attributes at all levels can make the number of questions too large. A fractional factorial design identifies specific combinations to present, with high confidence in the results. Fractional factorial designs are described in ISO 16336 and ISO/TS 16355-6.

NOTE 2 Concepts can be presented as textual descriptions simple profile cards, or with pictorial representations. A brand name or trademark can be used as one of the attributes. Pictorial representations reduce information overload, keeping the process more interesting and less fatiguing to the respondent, and are more realistic.

NOTE 3 Response scales can be ordinal rating, ordinal ranking, or price customer is willing to pay.

5) Field the questionnaires.

NOTE 4 Questionnaires can be done by personal interviews, computer applications or social media, mail, or telephone.

6) Analyze the results. Change attributes and levels to forecast and simulate customer preferences. Analysis of latent classes helps identify sub-segments in the market[5].

9.3.4 Case study of conjoint analysis and QFD

9.3.4.1 General

This case study is for the design of a new home climate controller[6]. Homes and businesses looking for eco-friendly climate control are key customers for this project. Determining key customers is described in ISO 16355-2:2017, 9.2.1. Other stakeholders include architects and heating and cooling retail/wholesale centers.

9.3.4.2 Interview questions

Key customers and stakeholders are interviewed regarding their use of a controller to set and maintain proper building temperature in different seasons. From these interviews, specific product attributes are selected for evaluation in a conjoint analysis questionnaire. These attributes included:

a) price (30 € 40 €, or 50 €);

b) display (analogue, digital, or voice);

c) brand (company L, company G, or company T).

9.3.4.3 Array of factors in trade-off conjoint analysis

Table 5 shows the layout of the trade-off array of the survey questions. Respondents are shown examples of the products to be tested (text descriptions, profile cards, or pictorial representations) and asked to rate or rank them, with a score of 1 for the most preferred and descending in value to the least preferred combination of product attributes. Here, the customer preference rating for each profile is recorded.

NOTE Additional profiles combining display, brand, and price can be added.

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Table 5 — Conjoint analysis profiles in questionnaire

Attribute	Level Ref #	Level Description	Profile #	Attribute levels Display	Attribute levels Brand	Attribute levels Price	Preference rating
Display	3	Analogue	1	1	1	1	9
	2	Digital	2	1	2	2	7
	1	Voice	3	1	3	3	5
Brand	3	L	4	2	1	2	6
	2	G	5	2	2	3	5
	1	T	6	2	3	1	6
Price	3	30 €	7	3	1	3	5
	2	40 €	8	3	2	1	7
	1	50 €	9	3	3	2	6

9.3.4.4 Analysis of results

Most statistical software packages include a conjoint analysis function. Spreadsheet programs can also do this with a linear regression function. In Table 6, the results show the influence of display, brand, and price. Price is the most important driver for the product with twice the importance of display type and brand, and that the analogue display, L brand, and 30 € price are the preferred combination of the attribute levels.

Table 6 — Conjoint analysis results

Attribute	Level Ref #	Level Description	Utility	Importance
Display	3	Analogue	0,778	
	2	Digital	−0,556	
	1	Voice	−0,222	0,258
Brand	3	L	0,445	
	2	G	0,111	
	1	T	−0,556	0,214
Price	3	30 €	1,111	
	2	40 €	0,111	
	1	50 €	−1,222	0,500

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9.4 Cluster analysis

Another approach to understand how customers structure their needs is cluster analysis[7]. In this process, customers are asked to sort into five piles cards on which customer needs are written. Cards placed in the same pile are then analyzed using cluster analysis to determine how "close" they are in importance, and from this the priority of needs can be identified.

9.5 Cultural dimensions

9.5.1 General

Culture dimensions identify the members of one group or category of people from others but variability among individuals within the same culture can be vast. Geert Hofsted likens variability among individuals to a bell curve and the differences between cultures is like a shift of the bell curve. Culture

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has several dimensions that affect how customers respond to surveys and behave during gemba visits. Models and scoring of these dimensions by Hofstede and others can help QFD teams understand customers better[8]. The cultural dimensions and scores are as follows.

1) Power Distance Index (PDI), this reflects the unequal distribution of power in society and how tolerated it is by subordinates.

2) Individualism (IDV), are people acting mostly for their own sake or is collectivism valued.

3) Masculinity (MAS), this deals with the distribution of roles between the sexes.

4) Uncertainty Avoidance Index (UAI), relates to the tolerance for uncertainty and ambiguity.

5) Long-Term Orientation (LTO), is long time or short time thinking valued.

9.5.2 Cultural dimension scores

Hofstede's scores were developed by analyzing company employees in more than 70 countries. The scoring scale is 1 - 100, with 50 at the midpoint and are organized as shown in Table 7.

Table 7 — Hofstede cultural dimension scoring

Cultural dimension	Low score (1 - 50)	High score (51 - 100)
PDI	Strives for equality and distribution of power	Accepts hierarchical order and one's place in it
IDV	Group is responsible for members in exchange for loyalty	Individual is responsible for their self
MAS	Cooperative, caring, consensus, quality of life rewards	Competitive, assertive, material rewards
UAI	Relaxed behavior and more tolerant of different perspectives	Rigid codes and discomfort with uncertainty
LTO	Traditional values and discomfort with new ideas	Future oriented and pragmatic about change

9.5.3 Cultural dimensions and QFD

PDI (power distance) and the UAI (uncertainty avoidance) has the largest influence on gemba visits, and to a lesser extent also the LTO (long term thinking). PDI can influence the way visited customers behave during a gemba visit. For example, in a culture with a high PDI, subordinates avoid expressing opinions that differ from their superiors, so to successfully perform a gemba visit in a high PDI culture, it is important to show integrity and in at least part of the visit, speak to different hierarchical levels separately.

EXAMPLE U.S. with respect to world averages are PDI (40/54) and UAI (46/62). These figures suggest that the importance of hierarchy is slightly higher than for Sweden and Germany, but because the UAI is much lower than Germany’s (65) and Brazil’s (76), although higher than Sweden’s (29), this indicates that in the U.S. there is a higher than average openness to the new and unproven. The gemba visits in US passed without problems, the participants showed a genuine interest in sharing their thoughts, as is consistent with the low UAI.

9.6 Factor analysis with covariance structure analysis

9.6.1 General

Customer satisfaction and customer dissatisfaction are both useful metrics in new product development, especially to measure customer loyalty[9]. Satisfaction metrics are useful in developing products that customers can differentiate from competitors'. Dissatisfaction metrics are useful in cost reduction efforts used in cost deployment and value analysis and engineering, as described in ISO 16355-5:2017, 10.4.4. This helps identify areas of removing over-engineered costs without creating unacceptable customer dissatisfaction. Satisfaction and dissatisfaction are similar to the Kano model categories of

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exciting quality and expected quality described in ISO 16355-5:2017, 10.3.4.4. Factor analysis is used to identify known satisfaction elements and is combined with covariance structure analysis to identify unknown additional satisfaction elements.

9.6.2 Factor analysis to classify functional requirements into satisfaction factors

Satisfaction elements, functional requirements, and non-functional requirements such as reliability, safety, price, economy, functionality, usability, and others are surveyed with customers using a Likert scale of 1 - 5 to measure very dissatisfied, dissatisfied, neutral, satisfied, or very satisfied. Pairs of factors can be grouped into one of four categories using factor analysis on the survey results.

1) Factor 1 only affects customer satisfaction.

2) Factor 2 only affects customer satisfaction.

3) Factors 1 and 2 together affect customer satisfaction.

4) Neither factors 1 or 2 affect customer satisfaction.

9.6.3 Covariance structure analysis

Covariance structure analysis helps to further quantify the degree to which certain elements contribute to customer satisfaction or dissatisfaction. This helps developers group those elements by the degree which contribute to satisfaction but not dissatisfaction or contribute to dissatisfaction but not satisfaction.

EXAMPLE A computer monitor is studied for which elements are important for customer satisfaction. Using a survey and factor analysis, factors are grouped as value factors (usability, functionality, price-competitiveness), reliability factors (assurance, reliability, safety, economy), and market factors (market penetration, availability). Covariance structure analysis showed the mutual effects between the factors. Functionality and usability showed high covariance with value (covariances of 0,96 and 0,94 respectively). This directed developers to optimize these functional requirements because the customer associated them with value. Availability and functionality showed high negative covariance with market penetration and reliability (covariances of −0,70 and −0,30 respectively). This directed developers to avoid too many new functions that could delay the product's launch or increase failures.

9.7 Fuzzy set theory and multi-attribute utility theory

9.7.1 General

When customers can benchmark their degree of satisfaction with competitors, product developers gain a deeper understanding of what it takes to succeed in the marketplace. Using the technique for order preference by similarity to ideal solution (TOPSIS) found in multi-attribute utility theory, fuzzy set theory is used to convert language data (ex. bad vs. good) into fuzzy numbers and then into crisp numbers. The following is described further in Reference [10].

9.7.2 Difficulties in scoring customer satisfaction

While marketers and new product developers strive to achieve best-in-class products, it is not always easy to get precise customer feedback on what this actually means. In cases where customer responses to surveys contain linguistic information (ex. bad, good, pretty good, great), it can be difficult to quantify what this means on a numerical scale, such as 1 - 10. Further complicating this is that the same linguistic terms could have different meanings in different situations. Fuzzy set theory developed by L. A. Zadeh is used to covert linguistic information into fuzzy numbers. Then a fuzzy scoring method can be used to convert the fuzzy numbers into crisp customer satisfaction scores. Multi-attribute decision making can be used to then determine customer preferences.

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9.7.3 Fuzzy sets

Fuzzy sets address the lack of crisp scores by assigning a range of values to membership in a set of numbers from 0,0 to 1,0. For example, if a customer need is "I have fun driving my car," it can be represented in a range of values from "boring" to "exciting" as shown in Table 8. This shows that a boring car has a membership value of $\mu_{boring}(boring) = 1$ and a value of $\mu_{exciting}(boring) = 0$.

Table 8 — Different levels of fun and their associated fuzzy membership values

Level of fun (x)	$\mu_{boring}(x)$	$\mu_{exciting}(x)$
Boring	1,0	0,0
Not worth mentioning	0,6	0,0
Moderate	0,4	0,2
Impressive	0,2	0,6
Exciting	0,0	1,0

9.7.4 Crisp scores

Converting membership in a fuzzy set into a crisp number requires setting an absolute reference which can be graphed as shown in Figure 1. The fuzzy left function represents the degree of boring by connecting the coordinates (0,1) and (1,0) and the fuzzy right function represents the degree of exciting by connecting the coordinates (0,0) and (1,1). The membership of boring to the absolute boring function μ_L(boring) is the maximum value of the intersection between the fuzzy number *boring* and the fuzzy left function. Thus, μ_L(boring) = 0,5 is calculated by drawing a horizontal line from the intersection. In the same way, the membership value of *boring* to *exciting* is the maximum value of the intersection between the fuzzy number *boring* to the fuzzy right function μ_R(boring) = 0,66. Then, the crispy score μ_T of the fuzzy number *boring* is calculated:

$$\mu_T(\text{boring}) = \frac{\mu_R(\text{boring}) - \mu_L(\text{boring}) + 1}{2} = \frac{0{,}66 - 0{,}5 + 1}{2} = 0{,}58 \quad (1)$$

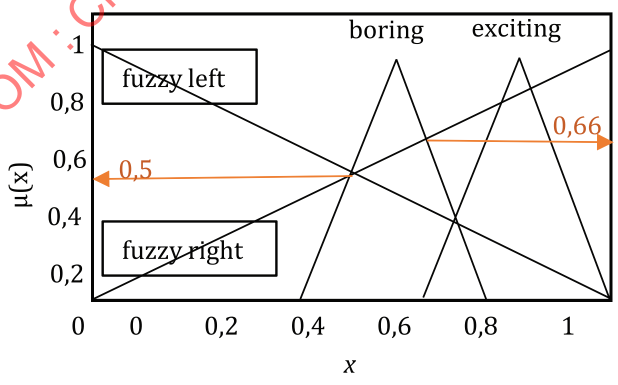

Figure 1 — Converting fuzzy numbers into crisp scores

Once all the fuzzy numbers have been converted to crispy numbers, a multi-attribute decision making technique can be applied. In this way, the crisp scores for "fun to drive" from boring to exciting are calculated as 0,04, 0,33, 0,58, 0,66, and 0,96 for boring, not worth mentioning, moderate, impressive, and exciting respectively.

9.7.5 Customer preferences by benchmarking competition

In the weighted quality planning table described in ISO 16355-4:2017, 12.2 these crisp scores can be used to benchmark competitive or alternative products.

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9.7.6 Failure mode and effects analysis using fuzzy multiple-objective decision models

When cost and schedule constraints make it impossible to test all raw materials and manufacturing processes for quality and reliability, these can be prioritized according to their impact on functional requirements and quality characteristics using methods such as failure mode effects analysis (FMEA) which is detailed in ISO 16355-5:2017, 10.4.5.8 and ISO/TR 16355-8:2017, 9.8 and 13.4. In addition to identifying what is critical to quality is the need to minimize technical difficulties which can be vague and subjective during the design phase. Fuzzy multiple-objective decisions models have been used to establish fuzzy relationships in the functional requirements failure modes matrix detailed in ISO 16355-5:2017, 10.4.5.6[11].

9.8 Market position analysis

9.8.1 General

Quantitative information regarding competitors' positions in the market are used to show current and trending changes in their advantages in market space.

9.8.2 Types of market positioning

9.8.2.1 Head-to-head positioning

Competing with the same product attributes in the same target markets.

9.8.2.2 Differentiation positioning

Competing in a smaller or more focused market niche that is less competitive. This can also be used with new Lanchester strategy for the weak, which is described in ISO 16355-2:2017, 9.1.2.6.

EXAMPLE Florida Blue (BCBSF) is examining trends in potential changes in health care insurance policies at the federal and state level in the U.S. Based on proposed legislation, they examine which competitors are trending towards broad (head-to-head) or narrow (differentiation) market focus, and low cost leadership of higher cost differentiation policies. They see their current position as trying to be in the middle, which carries the risk that the more focused competitors will take market share from them. Senior marketing and operations executives are convened to discuss and determine the future market position. Using the analytic hierarchy process (AHP), they are able to organize their debate, see opposing positions, and reach consensus despite dissonant opinions. Four strategies are prioritized as shown in Table 9 and a clear winning strategy identified that could be clearly communicated to the entire organization[37].

Table 9 — Market position analysis for healthcare insurer

Target scope	Advantage	
	Low cost	Product uniqueness
Broad (industry wide)	Cost leadership strategy Competitor U BCBSF	Differentiation strategy Competitor A
Narrow (market segment)	Focus strategy (low cost)	Focus strategy (differntiation)

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9.9 Market segmentation using cross tabulations

9.9.1 General

A cross tabulation is a method of presenting and relating data having two or more variables. This is a more objective approach than subjective estimates of market size and segments[12]. Cross tabulations can be used to pair specific customer demographic attributes such as age, sex, income, and others to better understand which customer segments are to be investigated more thoroughly in the customer segments table during new product development or in sales and marketing efforts at product launch. Customer segments table and gemba investigation methods are described in ISO 16355-2:2017, 9.2.2. Sales and marketing efforts are described in ISO/TR 16355-8:2017, Clause 15.

9.9.2 Types of cross tabulations

9.9.2.1 Raw data

The actual counts or responses to the specific questions asked.

9.9.2.2 Row percentages

Answers expressed as percentages and displayed horizontally, as shown in Table 10.

Table 10 — Cross tabulation by row percentage

Frequency of Use by Age Range (raw data)					(row percentages)				
Age of head of household (years)	**Once a week or more**	**2 or 3 times a month**	**Once a month or less**	**Total**	**Age of head of household (years)**	**Once a week or more**	**2 or 3 times a month**	**Once a month or less**	**Total**
24 or less	144	52	19	215	24 or less	67,0 %	24,2 %	8,8 %	100 %
25 - 39	46	58	29	133	25 - 39	34,6 %	43,6 %	21,8 %	100 %
40 or older	82	69	87	238	40 or older	34,5 %	29,0 %	36,6 %	100 %
Total	272	179	135	586	Total	46,4 %	30,5 %	23,0 %	100 %

9.9.2.3 Column percentages

Answers expressed as percentages and displayed vertically, as shown in Table 11.

Table 11 — Cross tabulation by column percentage

Frequency of Use by Age Range (raw data)					(column percentages)				
Age of head of household (years)	**Once a week or more**	**2 or 3 times a month**	**Once a month or less**	**Total**	**Age of head of household (years)**	**Once a week or more**	**2 or 3 times a month**	**Once a month or less**	**Total**
24 or less	144	52	19	215	24 or less	52,9 %	29,1 %	14,1 %	36,7 %
25 - 39	46	58	29	133	25 - 39	16,9 %	32,4 %	21,5 %	22,7 %
40 or older	82	69	87	238	40 or older	30,1 %	38,5 %	64,4 %	40,6 %
Total	272	179	135	586	Total	100,0 %	100,0 %	100,0 %	100,0 %

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9.9.2.4 Grand total percentages

Answers in each cell expressed as percentages of the grand total, as shown in Table 12.

Table 12 — Cross tabulation by grand total percentage

Frequency of Use by Age Range									
(raw data)					(grand total percentages)				
Age of head of household (years)	**Once a week or more**	**2 or 3 times a month**	**Once a month or less**	**Total**	**Age of head of household (years)**	**Once a week or more**	**2 or 3 times a month**	**Once a month or less**	**Total**
24 or less	144	52	19	215	24 or less	24,6 %	8,9 %	3,2 %	36,7 %
25 - 39	46	58	29	133	25 - 39	7,8 %	9,9 %	4,9 %	22,7 %
40 or older	82	69	87	238	40 or older	14,0 %	11,8 %	14,8 %	40,6 %
Total	272	179	135	586	Total	46,4 %	30,5%	23,0%	100,0 %

9.9.3 Uses of cross tabulations

Cross tabulations can be easily displayed in graphical presentations for more efficient communication to management. The choice of horizontal, vertical, or grand total tabulations make it easy to select the format that best corresponds to the attributes being analyzed. Customer segments can be prioritized based on the tabulations. Customer segment prioritization is described in ISO 16355-2:2017, 9.2.3.

NOTE 1 Results can be misleading if based on too small a sample size of the subject population. Sample size calculation is described in ISO 16355-4:2017, 11.5.

NOTE 2 A large number of attributes can create very large tables. For example, all possible pairs for 50 questions create 1 225 cross tabulations.

NOTE 3 Since only two or three variables can be tabulated at a time, some relationships might be hidden.

9.10 Multidimensional scaling (MDS)

9.10.1 General

This statistical technique spatially presents customer perception and preference in a visual mapping of competitive products as points in multidimensional space. MDS uses these terms[12].

a) Similarity judgments, where products or brands are rated in terms of similarities or differences.

b) Stress, which measures a lack of fit where a higher stress indicates a poorer fit.

c) R-square (R^2), which represents the proportion of variance in data explained by the MDS technique.

d) Spatial map, which is a multi-point geometric characterization of perceived similarities or differences in competing products and brands.

e) Coordinates on the spatial map, used to position the competing products.

f) Unfolding, which is a juxtaposition of products or brands and market segments in the same spatial map.

9.10.2 Conducting the MDS study

1) Formulate the problem in terms of how many variables to compare.

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2) Obtain input data. Input data includes direct (judgments) and derived (product attribute ratings using a sematic differential scale as described in ISO 16355-5:2017, 8.9.2) of perceptions and preferences.

3) Run MDS program on the input data. This is found in most commercial statistical packages. There are different types of MDS for different problems, but the classical approach is to use principal coordinates analysis (PCoA) which calculates the distance between products as:

$$d_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}; \quad (2)$$

4) Decide number of dimensions. The more dimensions, the lower the stress and better the fit, but it makes it more difficult to interpret the results.

5) Label the dimensions and interpret the map. The software will produce a 2-dimensional representation of the products with those closest to each other sharing the most similarities. Perceptual mapping helps interpret the correspondence of the dimensions.

6) Assess reliability and validity. The R-square is computed by the software and a value of 0,6 is minimally acceptable.

9.10.3 Case study on toothpaste

9.10.3.1 General

Toothpaste consumers are presented with advertisements claiming multiple benefits from various brands such as freshens breath, fights cavities, removes stains, whitens teeth, and others. MDS can be a valuable technique when developing a new product in a crowded market.

9.10.3.2 Obtain input data

Customers are asked to pairwise rate the similarities between ten different toothpaste brands, as shown in Table 13. The 1 - 7 ratings indicate a degree of similarity in the brands as perceived by the customer. The higher the number, the greater the similarity. Brands are identified and not compared with themselves.

NOTE As with any pairwise comparisons, the number of pairs that the respondent is presented grows quickly. The number of question pairs is calculated as $(n^2 - n)/2$. Ways to reduce the number of pairs are described in the analytic hierarchy process (AHP) technique in ISO 16355-4:2017, 11.6.

Table 13 — MDS similarity ratings grid

Similarity ratings of toothpaste brands										
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
A										
B	5									
C	6	7								
D	4	6	6							
E	2	3	4	5						
F	3	3	4	4	5					
G	2	2	2	3	5	5				
H	2	2	2	2	6	5	6			
I	2	2	2	2	6	6	7	6		
J	1	2	4	2	4	3	3	4	3	

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9.10.3.3 Create spatial map and label the dimensions

By examining the closeness of competing brands and their claims, ideal vectors can be drawn to label the customer perceived dimensions and where there is space to introduce a new brand. In Figure 2, opportunities for greater teeth whitening are possible.

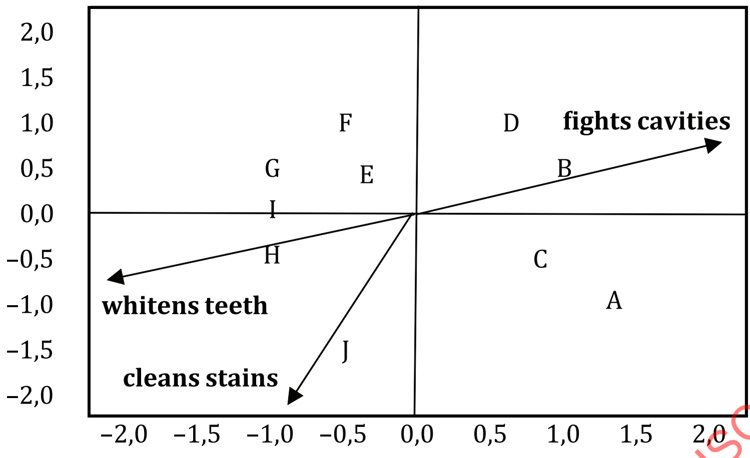

Figure 2 — MDS spatial map with labeled dimensions

9.11 Net promoter score (NPS)

9.11.1 General

Net promoter score®1) is a method to measure customer loyalty as the likelihood that a satisfied customer would recommend a product or service to a friend or relative. Customers express this as both a score on a 0 - 10 scale as well as by giving reasons why they selected such a score. The NPS score is the difference between the percentage of *promoters* (those responding with a 9 or 10) and the percentage of *detractors* (those responding with a 0 - 6). *Passives* are those who respond 7 - 8. Essentially, it predicts future business[13]. NPS is typically used to score companies and brand strength, but in the QFD process, it has been modified to analyze product attributes, as well[14].

9.11.2 NPS survey

The NPS survey is simple in that it asks the customer one question – how likely are they to recommend the product to a friend or relative. Then, it asks the customer to comment in their own words why they selected that score.

9.11.3 NPS survey results

9.11.3.1 The NPS survey responses are on a 0 - 10 scale. They are classified as follows.

a) 0 - 1, I would surely not recommend.

b) 2 - 3, I would rather not recommend.

c) 4 - 6, I don't know if I would recommend or not.

d) 7 - 8, I would probably recommend.

e) 9 - 10, I would absolutely recommend.

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1) NPS is a trademark of Fred Reichheld, Bain & Company and Satmetrix. This information is given for the convenience of the users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

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9.11.3.2 Calculating the NPS score

The calculation of the NPS score is as follows.

Net promoter score = % promoters – % detractors

9.11.3.3 Interpreting the NPS score

The NPS score is interpreted as follows.

a) Positive % value means everything is fine. For example, NPS of 40 % means that there are 40 % more promoters than detractors.

b) 0 % value means there are an equal number of promoters as detractors. Something is not right.

c) Negative % value means there are fewer promoters than detractors. This requires an immediate and focused response.

NOTE In all cases, the company can strive to convert detractors into passives, and convert passives into promoters.

d) Free responses are used as customer narratives and added to the customer voice table to be translated into customer needs. The customer voice table is described in ISO 16355-4:2017, 9.2.4.

9.12 Neural networks (NN)

9.12.1 General

A neural network uses computer-based learning to discover patterns between input and output data. In order to determine an overall satisfaction level, data is collected through two groups of surveys:

1) first, to discover the patterns and train the neural network;

2) second, to test how well the neural network has learned the patterns.

As each training survey is processed, the test survey adjusts the network to be closer to the correct response.

9.12.2 Preparing the surveys

NN surveys pose literal responses to why customers purchase a product. A common set of responses are:

a) definitely would purchase;

b) probably would purchase;

c) might or might not purchase;

d) probably would not purchase;

e) definitely would not purchase.

By assigning specific numerical values to the above responses, sensitivity analysis can be performed. Though ordinal 1 - 5 responses have been used, values with equal ratios between the levels are more precise[15]. These are described in ISO 16355-4:2017, 11.1. The number of survey questions is typically 50 - 80 customer needs, configured into three levels using affinity diagram and hierarchy diagram described in ISO 16355-4:2017, 10.2 and 10.3 respectively. As this is an opinion survey, 200 respondents for training the NN and another 200 for testing the NN are recommended. This number of input questions and respondents produces a large number of networks which are narrowed to 10 - 12 such that 80 % exhibit consistency between individual inputs and outputs.

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9.12.3 Interpreting the NN output

Neural network software is used to identify and test the patterns of customer needs and satisfaction level responses.

EXAMPLE A Department of Motor Vehicles (DMV) used NN to improve their customer service. Among the customer needs tested are the following.

a) Employees are courteous.

b) Employees are knowledgeable.

c) My time is respected.

d) Employees are concerned for me.

e) Forms are easy for me to complete.

f) I can complete my business in one visit.

The NN outputs helped the DMV understand the impact of each need on overall customer satisfaction, as shown in Figure 3. The Y-axis identifies the current level of satisfaction with each customer need. The X-axis identifies impact of improving each customer need on overall satisfaction.

EXAMPLE 7 % of the customers are satisfied with the DMV employees respecting their time. The impact of improving this is 0,84. Thus, a 10 % improvement in respecting their time would result in a 10 % × 0,84 = 8,4 % improvement in customer satisfaction.

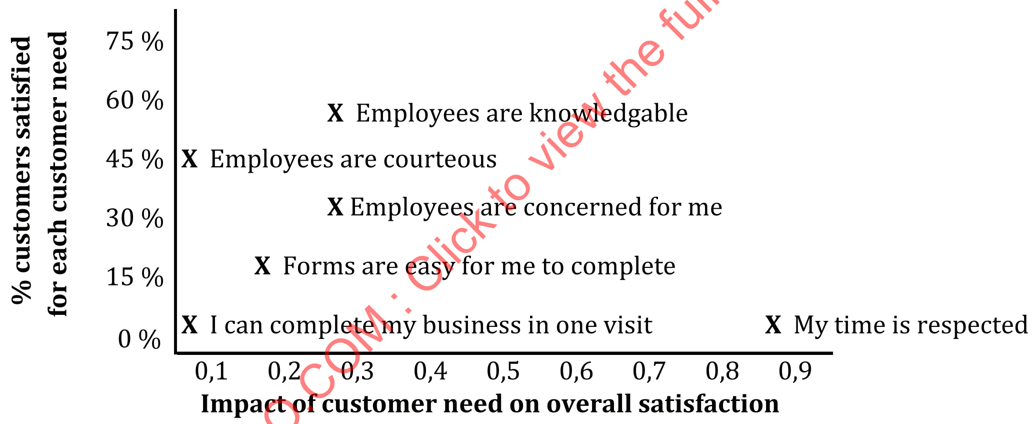

Figure 3 — Impact of customer needs on overall customer satisfaction

9.12.4 Using the NN output in a QFD study

The NN results help the QFD create a solution strategy by focusing efforts on those needs that will yield the highest impact in overall satisfaction. The maximum results are achieved when the current satisfaction level is low and the impact is high.

EXAMPLE The DMV investigated improvements in respecting customer time by reducing wait times for common transactions through customers inputting much of the required information online and informing process status to customers on more complex transactions.

9.13 Quantification methods (QM)

9.13.1 General

The quantification methods were developed by Chikio Hayashi to quantify category data and are used in evaluating questionnaire results[16]. Four different methods have been defined according to the type of target variable and respondent variable. There are two major types – target variables (also

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called dependent variables, y variables, response variables) and explanatory variables (also called independent variables, x variables, regressors). The target variable is usually the outcome of some observation or event, and the explanatory variables attempt to explain the variance among outcomes. When there are three or more variables, we can use multivariate analysis to look at these relationships at the same time. Sometimes we can find a direct causal relationship between variables and sometimes we can find that two variables do not have a causal relationship but correlate with a third variable, and we need to study its influence in order to explain and predict other similar scenarios.

Each of these variables can be either numerical (interval scale or ratio scale) or category (nominal scale or ordinal scale). We sometimes find “near-ordinal” nominal scales and “near-interval” ordinal scales, as well. Table 14 suggests different statistical methods depending on the type of variables. QM III is most widely used in QFD[17].

Table 14 — Quantification methods and uses

Target Variable?	Type of Respondent Variable		Statistical Method
	Target	Explanatory	
Yes (to explain cause & effect)	Numerical	Category	Quantification Method I
	Numerical	Numerical	Multiple Regression
	Category	Category	Quantification Method II
	Category	Numerical	Discriminant Analysis
No (data reduction, theory-generation)	—	Category	Quantification Method III
			Correspondence Analysis
	—	Numerical	Principle Component Analysis
			Factor Analysis

9.13.2 Quantification method III (QM III)

In a QFD house of quality, when there is a need to reduce a large number of customer needs (category-type variables) to a more manageable set, QM III can be applied to determine which one-to-one and one-to-many corresponding items can be temporarily excluded. This can also reduce the time spent on affinity diagram and hierarchy diagram analysis, described in ISO 16355-4:2017, 10.2 and 10.3.

9.13.3 Applying QM III to a 2-dimensional QFD matrix

Suppose that there are two dimensions, X and Y, each of which has three items, X_i, Y_j (i, j = 1, 2, 3). In the house of quality, the Xs would be customer needs and the Ys would be functional requirements. Items X_is and Y_js are respectively related to scores x_i and y_j. This step signifies the quantification. Then we get the data shown in Table 15. The O symbols denote a correspondence between the X and Y items. The O symbols can be replaced with pairs of scores and their frequency as input data, as shown in Table 16[18].

Table 15 — QM III data table

	Y Item	Y_1	Y_2	Y_3
X item	score	y_1	y_2	y_3
X_1	x_1	O		
X_2	x_2	O		O
X_3	x_3		O	O

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Table 16 — QM III input data

	Y Item	Y_1	Y_2	Y_3	
X item	score	y_1	y_2	y_3	freq.
X_1	x_1	(x_1, y_1)			1
X_2	x_2	(x_2, y_1)		(x_2, y_3)	2
X_3	x_3		(x_3, y_2)	(x_3, y_3)	2
	freq.	2	1	2	5

Averages of scores are assumed to be zero:

$$\left(x_1 + 2x_2 + 2x_3\right)/5 = 0, \tag{3}$$

$$\left(2y_1 + y_2 + 2y_3\right)/5 = 0. \tag{4}$$

Variances are assumed to be unity:

$$\left(x_1{}^2 + 2x_2{}^2 + 2x_3{}^2\right)/5 = 1. \tag{5}$$

$$\left(2y_1{}^2 + y_2{}^2 + 2y_3{}^2\right)/5 = 1. \tag{6}$$

Then, the correlation coefficient ρ is given by

$$\rho = \left(x_1 y_1 + x_2 y_1 + x_2 y_3 + x_3 y_2 + x_3 y_3\right)/5. \tag{7}$$

QM III determines scores so that Formula (7) has the maximum value under the restriction of Formulas (3), (4), (5) and (6). Then, we get the following formula:

$$\begin{bmatrix} (3/4)-\lambda^2 & & +(1/4) \\ & (1/2)-\lambda^2 & +1/\left(2\sqrt{2}\right) \\ (1/4) & +1/\left(2\sqrt{2}\right) & +(1/2)-\lambda^2 \end{bmatrix} \begin{bmatrix} \sqrt{2}\,y_1 \\ y_2 \\ \sqrt{2}\,y_3 \end{bmatrix} = \mathbf{0} \tag{8}$$

where $\lambda = \rho$.

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This can be solved with respect to λ^2 as follows:

$$16\left(\lambda^2\right)^3 - 28\left(\lambda^2\right)^2 + 13\left(\lambda^2\right) - 1 = \left[\left(\lambda^2\right) - 1\right]\left[16\left(\lambda^2\right) - 12\left(\lambda^2\right) + 1\right] = 0. \quad (9)$$

Then, we have following three solutions with respect to λ^2:

$$\begin{aligned} &\lambda^2 = 1, \\ &\lambda^2 = \left(3 \pm \sqrt{5}\right)/8 \\ &\quad \approx 0{,}654\,51; 0{,}095\,49. \end{aligned} \quad (10)$$

QM III excludes scores with respect to $\lambda^2 = 1$ because their component values are all same, that is, $y_1 = y_2 = y_3 = 1/\sqrt{5}$ in this case. Substituting the second and the third values of λ^2 into Formula (8), we have:

$$\begin{aligned} &\left[\left(-3 \pm \sqrt{5}\right)/8\right]\left(\sqrt{2}\, y_1\right) - \left(\sqrt{2}\, y_3\right)/4 = 0 \\ &\left[\left(-1 \pm \sqrt{5}\right)/8\right] y_2 - \left(\sqrt{2}\, y_3\right)/\left(2\sqrt{2}\right) = 0 \\ &\left(\sqrt{2}\, y_1\right)/(-4) - y_2/\left(2\sqrt{2}\right) - \left[\left(-1 \pm \sqrt{5}\right)/8\right]\left(\sqrt{2}\, y_3\right) = 0. \end{aligned} \quad (11)$$

These formulas yield the following scores of Y items,

$$\begin{aligned} &y_1 \approx \quad 1{,}144\,12, \quad 0{,}437\,02 \\ &y_2 \approx -1{,}414\,21, \quad 1{,}414\,21 \\ &y_3 \approx -0{,}437\,02, \quad -1{,}144\,12 \end{aligned} \quad (12)$$

Finally, we can obtain scores of X items from Formulas (10) as follows:

$$\begin{aligned} &x_1 \approx \quad 1{,}414\,21, \quad 1{,}414\,21 \\ &x_2 \approx \quad 0{,}437\,02, \quad -1{,}144\,12 \\ &x_3 \approx -1{,}144\,12, \quad 0{,}437\,02 \end{aligned} \quad (13)$$

We obtain the two-dimensional table as shown in Table 17 by sorting each items of Table 15 with respect to the 2nd eigenvalue. These can be visually displayed as a scatter diagram as in Figure 4 which can be used to structure the X and Y items.

Table 17 — Two-dimensional table sorted by scores belonging to the 2nd eigenvalue

	Y Item	Y_2	Y_3	Y_1
X item	score	−1,414 2	−0,459 0	1,144 1
X_3	−1,144 1	0	0	
X_2	0,437 0		0	0
X_1	1,414 2			0

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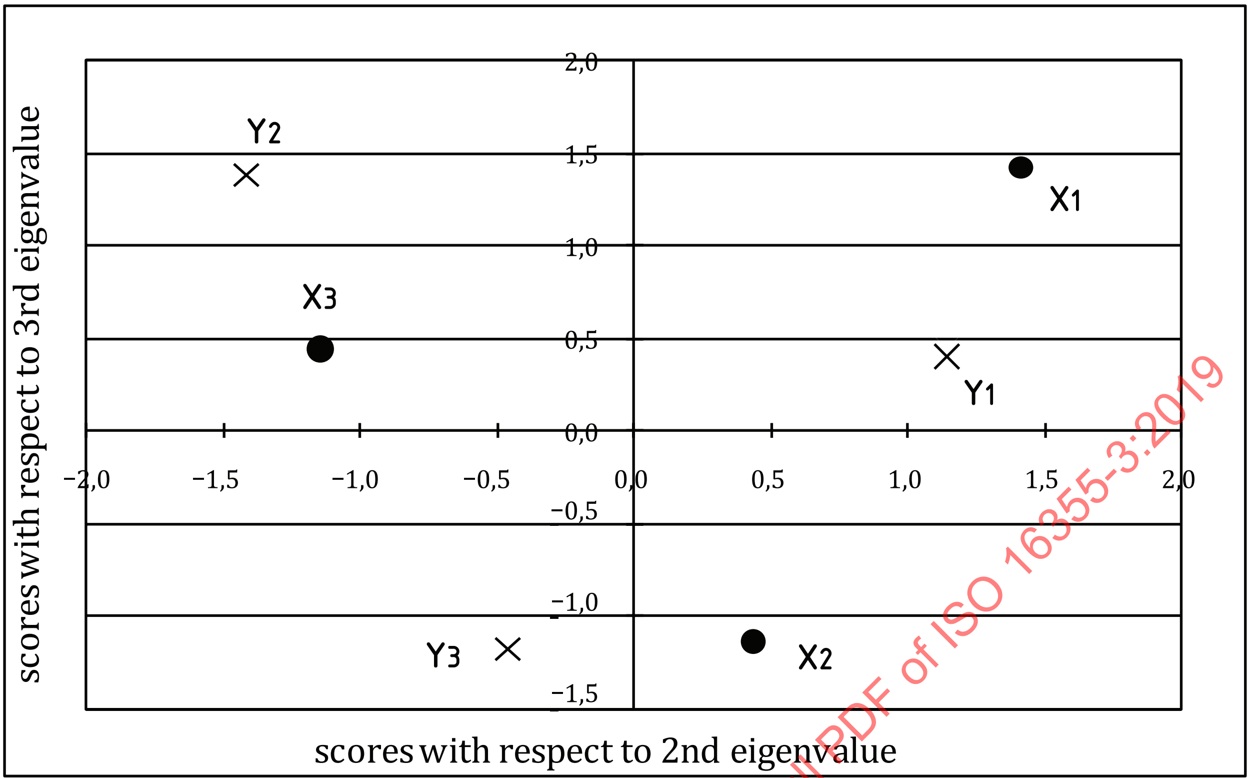

Figure 4 — QM III values scatter diagram

EXAMPLE A Japanese regional tourist board wants to improve information available to sightseeing visitors. Their initial analysis includes a large number of customer needs while sightseeing and a large number of information content, having both one-to-one and one-to-many correspondences, as shown in Table 18. These are further detailed into information related to GPS location, contact information, price, and other types of information. For generally encountered scenarios, scatter diagrams of eigenvectors are created to show which information is most useful. Further analysis with scatter diagrams as shown in Figure 5 allowed the tourist board to identify unusual scenarios, such as health and other problems, and develop information for that as well[19].

Table 18 — Correspondence table of tourist scenarios and information requirements

No.	Customer need and scenario	Information contents	Correspondence
1	I want to go to hot spring	The closest hot spring	1
2	I want to go to hot spring	The quality of hot spring	1
3	I want to have a meal	Restaurant catering to families	1
4	I want to have delicious food	Restaurant with local food	1
5	I want to stop my car	Parking place	1
. . .	. . . .		
. . .	. . . .		
. . .	. . . .		
836	I want to enjoy hot spring	Massage info	1
837	I want to enjoy hot spring	Beauty-treatment clinic info	1
838	I want to decide one day schedule	Transportation time	1
839	I want to decide one day schedule	Word-of-mouth info	1
840	I want to decide one day schedule	Average time needed for visit	1

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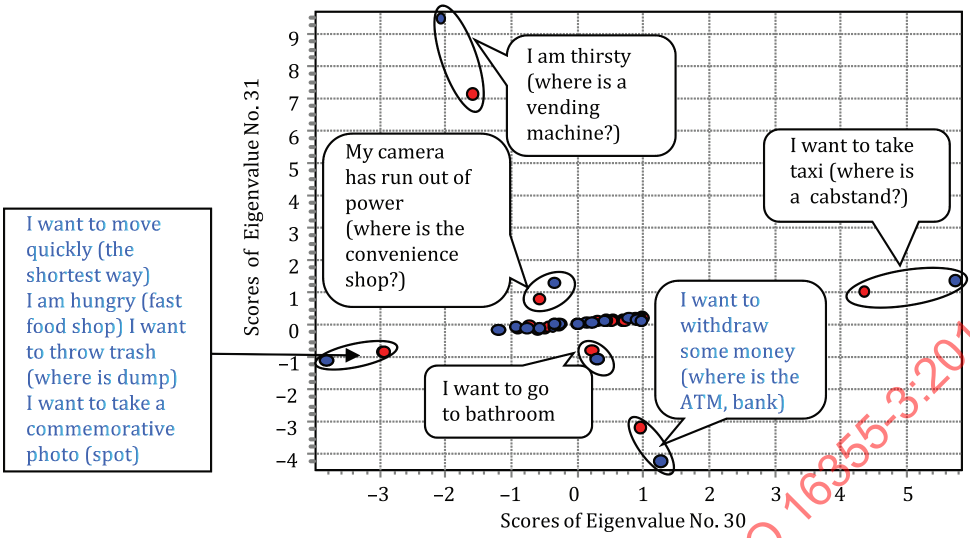

Figure 5 — QM III scatter diagram for tourism

9.14 Regression analysis

9.14.1 General

Regression analysis is a statistical method used to predict scores on one variable based on their correlation with scores on another variable. Regression works by fitting a set of data points to a curve and minimizing the distance from the points to the curve. It also estimates the uncertainty of the curve, probable slope and y-intercept, and outside influences such as other product characteristic or customer irrationality. This is important in QFD studies when the product development team is setting a target performance level for a product characteristic or requirement and there are exponential levels of cost compared to more linear levels of subjective customer satisfaction scores. An example of this in automobiles is maximum speed as illustrated in Figure 6 where the customer evaluations of performance level off to the point they are no longer perceivable but the cost to achieve higher performance grows rapidly[20].

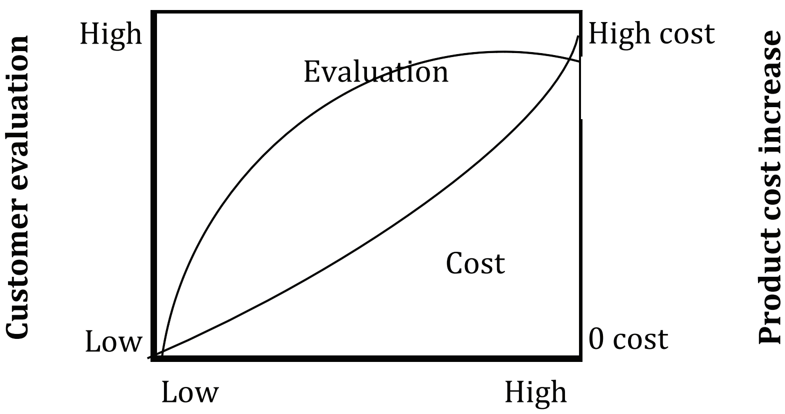

Figure 6 — Subjective evaluation of car speed vs cost increase

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9.14.2 Regression analysis in QFD

Either the maximum value table (ISO 16355-5:2017, 9.2) or the customer needs – functional requirements matrix (house of quality) (ISO 16355-5:2017, 9.3.6) can supply the regression variables. The variables in QFD to be regressed are the following.

a) The dependent *y* variable is the degree of satisfaction for each product-independent customer need, as defined in ISO 16355-1:2015, 3.3 and ISO 16355-4:2017, 9.1.3.3. The degree of customer satisfaction with the current, competitive, and proposed new product is measured on a 1-10 scale, using the mean value of customer responses.

b) The independent *x* variables are the technology independent functional requirements, as defined in ISO 16355-1:2015, 3.4 and ISO 16355-5:2017, 9.3.6.2.2. The maximum value table will have only a few variables, but If the house of quality includes a large of variables, use the ones where the relationship is extremely strong and very strong, as described in ISO 16355-5:2017, 10.2.1. Values can be actual performance values or a rating.

NOTE 1 If the data between the *y* and *x* seem random, consider eliminating the *x* functional requirement.

NOTE 2 The statistical significance of a QFD model can evolve over successive generations of the product. For the first use on a new product, as few as seven data points can be sufficient. With more variables or more competitive products to compare, the sample size increases. For calculating sample size, see ISO 16355-4:2017, 11.5.

9.14.3 Regression data

9.14.3.1 Input data

The customer assessment of current (1 and 2), competitive (A, B, C1, C2), and proposed products relative to need 1, as well as the actual performance of functional requirements *x*1 and *x*3 of the current, competitive, and proposed products are measured, as shown in Table 19. The values are entered into a statistical software application.

9.14.3.2 Output data

The regression statistics are outputted, as shown in Table 20.

Table 19 — Regression data

	Customer need 1 satisfaction level (*y*1)	Functional requirement performance level (*x*1)	Functional requirement performance level (*x*3)
Competitor C2	4,7	556	2,5
Competitor C3	5,5	556	2,2
Competitor B	5,6	554	2,15
Competitor A	6,7	582	1,8
Current product 1	6,7	566	1,9
Current product 2	7,8	575	1,65
Proposed product	8,9	604	1,4

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Table 20 — Regression statistics

Regression statistics						
Multiple R	0,99					
R-square	0,97					
Adjusted R-square	0,96					
Standard Error	0,28					
Observations	7					
Analysis of variance	df	Sum of squares	Mean square	F	Significance F	
Regression	2	12,24	6,12	76,32	0,00	
Residual	4	0,32	0,08			
Total	6	12,56				
	Coefficients	Standard error	t statistic	P-value	Lower 95 %	Upper 95 %
Intercept	7,81	9,39	0,83	0,44	−18,17	33,79
Functional requirement *x*1	0,01	0,01	0,67	0,53	−0,03	0,05
Functional requirement *x*3	−3,43	0,70	−4,91	0,00	−5,38	−1,49

9.14.3.3 Interpreting the output

1) The F value of 76,32 and the significance of 0,00 indicate the model is statistically significant.

2) The adjusted R-square value indicates that 96 % of the value of *y*1's assessment can be predicted by the performance levels of functional requirements *x*1 and *x*3.

3) The t statistic with an absolute value of >3 indicates the certainty of the fit of the slope. The low value for *x*1 of 0,67 suggests additional analysis, such as adding or removing other functional requirements *x* in the analysis, looking for interactions between the functional requirements, and testing for non-linear assumptions.

NOTE Defining functional requirements to be technology independent helps avoid interactions.

9.14.3.4 Using the regression output in the QFD study

When using regression analysis to test the correlations between customer perceptions of current, competing, and proposed products, a poor statistical fit can suggest the following.

a) Customer perceptions are driven by unknown product characteristics.

b) The influence of advertising messages or brand strength.

c) All competing products fall within the same perceptible range and the customer need will not be differentiating enough, as long as it meets some minimal degree of satisfaction. In other words, more is no longer "better" in the customer's point of view. This can also be tested using the new Kano model described in ISO 16355-5:2017, 10.3.4.4.3.

d) Uncontrollable factors or "noise" such as the environment or experience of the user. Noise factors are described in ISO 16336 and ISO/TS 16355-6.

The regression statistics can also be substituted in the house of quality.

a) The relationship weights and symbols can be replaced with the y = f(x) transfer function.

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b) The adjusted R-square value can replace the current, competitor, and plan values in the quality planning table (ISO 16355-4:2017, 12.2).

c) The transfer function can be used to calculate the target performance values in the design planning table (ISO 16355-5:2017, 10.3.4.1).

NOTE The use of regression analysis to augment the QFD study increases the time, effort, and the need for accurate data collection and assessment. As QFD studies are updated in future product generations, the importance of this augmentation grows.

9.15 Repertory grid technique

9.15.1 General

The role construct repertory grid technique was developed in the 1950s by George A. Kelley, based on his theory of personal constructs, a psychotherapy and diagnosis tool used to understand how people distinguish between known and new people and objects in their environment. It has evolved from a clinical therapy to broader applications in environmental studies, education, healthcare, business, and quality management[36].

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9.15.2 The repertory grid technique process

a) Identify items (objects) in the target customer's personal environment from which product characteristics will be determined.

NOTE 1 Prioritizing customers and applications is described in ISO 16355-2:2017, 9.2.2.2 and 9.2.3.

NOTE 2 The sample size of the number of subjects is determined according to margin of error tolerable and confidence level desired. This is described in ISO 16355-4:2017, 11.5.

EXAMPLE A group of college students between 19 - 28 years old (70 % male, 30 % female) at a German university are selected in a study of smartphones. This demographic of education, age, and sex approximated the actual smartphone owners.

b) Organize an interview in which target customers (subjects) are presented with three product characteristics (called a triad) to be grouped as two similar and one dissimilar (called the contrast pole) and to describe the important characteristic that delimits them.

NOTE 1 To reduce the number of objects shown, a subset can be used. The subset can be selected by the target customer, thus assuming that with enough subjects responding, all possible triads can be evaluated.

NOTE 2 Working objects can be replaced with mock-ups and specification sheets. This is useful in new product development when working models of new technology are not available for testing.

EXAMPLE Ten smartphones from among the top 50 are selected. To remove color and price from the decision, they are all black in color and price is not given. Subjects are asked to select and examine five of them using the triad technique and to explain the important delimiting characteristic. According to the interview the desired characteristic is determined and a polar opposite adjective is selected to create a survey. For example, square corners (undesired) vs round corners (desired), complicated to use (undesired) vs easy to use (desired), heavy weight (undesired) vs light weight (desired), and others organized into 24 construct pairs.

c) Present target customers with products in a simulated purchase decision and have them score using a multi-level rating scale. Average scores for all objects against all characteristics or constructs by all customers.

NOTE Scoring can be done by customers (subjects) examining all the objects, not just the subset.

EXAMPLE In the smartphone study, the scoring is based on a count of the number of entries of a construct pair for each phone by a single customer. For example, round is entered 16 times, easy to use 12 times, light weight 9 times. The number of entries for all phones for all constructs are then averaged for all customers, as shown in Table 21.

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Table 21 — Repertory grid for smartphone (partial)

Smartphone model											
L7	**S10**	**L1**	**N75**	**HD**	**S2**	**B80**	**HTP**	**N70**	**AI4**	**undesired characteristic**	**desired characteristic**
1,8	1,2	5,9	5,1	5,8	2,1	5,4	1,3	6,3	3,8	square corners	round corners
4,7	3,5	4,3	5,0	5,0	3,6	5,5	4,4	4,8	5,1	complicated to use	easy to use
2,7	2,5	6,0	5,7	5,0	2,8	6,4	4,0	6,4	4,9	heavy weight	light weight

d) Benchmark products of repertory grid against actual sales figures. This helps explain why some models are more popular among certain market segments.

NOTE These scores can also be used to understand sub-segments of the market.

EXAMPLE In the smartphone example, the frequency distributions for the top three models preferred by men are B80, AI4 and HD, and by women L7, B80 and HD.

9.16 Text analytics and text mining

9.16.1 General

Text analytics and text mining are used to extract more detailed and defined information from customer online reviews of products and services. The increasing availability of such reviews in social media and other digital formats makes such mining difficult to do with labor-intensive manual analyses. Text analytics unlocks hidden information and creates new knowledge and opportunities for new product developers. To derived high quality information, information retrieval, data mining, machine learning, statistics, and computational linguistics are employed on large data sets of customer reviews[21]. Text analytics steps used in QFD include text clustering and text mining[22].

9.16.2 Text clustering

Text clustering is used to categorize customer segments, and classify, filter, visualize, document, and index customer language. Different algorithms are used to perform these tasks. *K*-medoid and *k*-means clustering algorithms are used to determine an optimal subset of documents by clustering them according to similarity of key items derived through an iterative examination of the documents, using the following steps[23].

1) Preprocess freeform text according to word frequency using techniques such as term frequency (TF) or inverse document frequency (IDF).

2) Convert text to numeric data in a document-term matrix.

3) Determine number of clusters (k).

4) Define similarity method.

5) Normalize attributes.

6) Calculate similarities or distances.

7) Let d be the distance measure between instances. Select k random instances $\{s_1, s_2, \ldots s_k\}$ as seeds.

8) Until clustering converges or other stopping criterion:

For each instance x_i

Assign x_i to the cluster c_j such that $d(x_i, s_j)$ is minimal.

(Update the seeds to the centroid of each cluster.)

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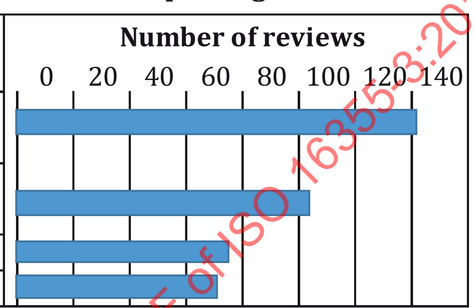
For each cluster c_j

$$s_j = \mu(c_j). \tag{14}$$

EXAMPLE User reviews for a diaper bag included both 1 - 5 review stars, descriptions of good product characteristics such as stylish, lots of pockets, and bad characteristics such as poor quality, too small. Freeform text included comments such as "I selected this bag because I thought it is kind of cute," and "the front pockets are small and flat," among the 232 user reviews examined. Text process software is used to calculate the TF-IDF counts. The number of reviews using these words are incorporated into the QFD analysis to prioritize customer needs such as I can fit many things, Easy to clean, and others as shown in Table 22 as well as product requirements such as multipurpose pockets, size, and others.

Table 22 — Extracted customer needs for diaper bag

Clusters	Customer needs	Number of reviews
0, 1, 2, 5, 7, 9, 12, 15, 16, 19, 21, 24	I can fit many things	
0, 1, 7, 8, 10, 17, 21, 23	Options to carry the bag	
6, 8, 12, 17, 21	Easy to clean	
3, 11, 13, 14, 16, 17	I want to keep things organized	



9.16.3 Topic modelling

Topic modelling is used for exploring hidden patterns in collections of documents. The idea behind topic modelling is to group similar documents within the same cluster. When considering the dynamic nature and increasing size of customer reviews by time, product, or service providers, topic modelling provides a mechanism which periodically categorizes reviews under topic groups and reduces the time complexity of analysis of the VoC in a QFD study.

Topic modelling approaches such as Latent Dirichlet Allocation (LDA) treats each review (document) as a mixture of topics, and a topic as a distribution over a set of words[24]. By using special algorithms, LDA turns the association between the words and documents into word–topic and topic–document associations separately. Word–topic association generates relative frequencies of the words which highlight the main features for a specific topic. Topic–document associations indicate many things about customers' feeling good and looking good issues. Topic scores obtained from topic–document associations are used to determine the representative documents for each topic. These documents are considered as the representative VoC for extracting customer needs[25].

EXAMPLE More than 80,000 online customer reviews on Italian restaurants are analyzed by LDA in order to group them as topics. After retrieving the freeform text data and converting it into an applicable format by using text processing software, the LDA procedure is implemented to extract topics in order to categorize reviews under particular groups (topics), and generate representative samples for each topic. The topic–word matrix, one of the two outputs of LDA application, presented the most frequent words in each topic in descending order. For example, topic 0 included such words as menu, item, option, lunch, order, offer, try, time, soup and dish. Topic 1 included salad, olive, dress, love, garden, mom, soup, place, concept, good. These words give some idea about the concepts covered by the corresponding topic. The second output of LDA, document–topic matrix, helped developers highlight the most representative documents (reviews) of topics for qualitative analysis. For example, topic 0 and its representative reviews are used to extract customer needs such as I want variety in the menu, my food is to be served as it looks like on the menu, menu notes preservatives used in the food, and I want to have different drink options.

NOTE In QFD, customer needs are product-independent as described in ISO 16355-4:2017, 9.2. The above example can be further refined as I want to select a food according to my mood, I want to know how my food looks before I order it, I want to make sure the food does not contain harmful additives, and I want to select a drink that compliments my food. Menu variety, menu illustrations, food preservatives, and drink variety are product attributes or functional requirements as described in ISO 16355-5:2017, 9.2. Product-independent customer needs avoid problem of too many menu varieties that cause frustration, many menu varieties but none are desirable, and others. Product-independent customer needs also promote innovation such as a menu-less restaurant, design-your-own dishes, and others.

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10 Deployment to next stage

10.1 Customer needs related information

The quantitative assessments of the voice of the customer are combined with the non-quantitative information described in ISO 16355-2, and then analyzed as described in ISO 16355-4.

10.2 Product related information

Quantitative assessments that produce information related to product, service, process, software, pricing, and other operational characteristics flow into downstream deployments as follows.

a) Functional requirements, functions, and performance information are described in ISO 16355-5.

b) Functional requirement parameters made robust due to user application conditions are described in ISO 16336 and ISO/TS 16355-6.

c) Product parameter tolerances made robust due to user application, competitive pricing, or manufacturing error are described in ISO 16337.

d) Production, sales, distribution, support, and other commercialization information are described in ISO/TR 16355-8.

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Annex A
(informative)

Using sampling surveys

A.1 General

Sampling surveys are used in several of the methods and tools in this document. These surveys are used to collect information about a population by using statistical and quantitative analyses of a portion or sample of that population. Generally, collecting information about a sample population is more efficient and cost effective than collecting information about the full population. To assure the quality and validity of the information and the interpretation of the information, it is important to follow a rigorous process, as described in this generic statistical business process model of the United Nations Economic Commission for Europe[26].

A.2 Methods used in sampling surveys

A.2.1 Clarification of the target population

Population of interest in the research project to which inferences are to be made. The target population refers to the entire group of units (individual or objects) for a survey to which the survey data are to be used to make inferences. It defines those units for which the findings of the survey are meant to generalize.

NOTE 1 Survey sampling concentrates solely on applications with a finite number of items in the population. The number of items could be very large (for example, hybrid automobiles in Europe, artefacts in a museum, sheep in New Zealand) but their number is finite. The number of items in the population is generally denoted as N. The specific value of N is not always known explicitly prior to conducting the survey.

EXAMPLE 1 The registry of citizens of a country is an example of a finite population with a known size.

EXAMPLE 2 Although generally the population size N is known in advance, this situation need not be the case. For example, the proportion of hybrid cars is of interest and observations could be taken at a checkpoint (e.g., toll booth or toll plaza). The number of cars that pass through the booth on a given day would not be known in advance, although the investigators would likely have a rough idea of the number from previous history. Perhaps a digital photo is taken of a select number of these vehicles to determine if they are hybrid cars.

NOTE 2 This definition is a combination of ISO 3534-4:2014, 3.1.1 and 3.1.2 and ISO 20252:2012, 2.66.

A.2.1.1 Subpopulation

Well-defined subset of the population.

NOTE 1 Sample surveys often have multiple objectives. Although the primary objective can concern the population as a whole, it is possible that select subsets are also of interest. For the example, hybrid vehicles or alternatively, sub-compact automobiles comprise subpopulations that can warrant particular interest. In some situations, the actual size of the subpopulation is unknown (e.g., number of teen-aged children among tourists visiting EuroDisney) and the interest can centre on estimating this value.

NOTE 2 This definition is taken from ISO 3534-4:2014, 3.1.3.

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A.2.1.2 Superpopulation

Expanded population that includes the population of interest.

NOTE 1 For inferential or assessment purposes, it can prove useful to imagine that the population of interest is embedded in a larger population having the base population as a special case. Such a theoretical construct facilitates the development of optimal sampling designs and allows the calculation of sampling design properties. The population of values can be treated as a random sample from a hypothetical superpopulation as opposed to a set of fixed values from which random selection is used to constitute a sample. According to Reference [27], the superpopulation concept can be given several interpretations. One of the interpretations is that the finite population is actually drawn from a larger universe. This is the superpopulation concept in its purest form. The superpopulation approach is a useful device for incorporating the treatment of non-sampling errors in survey sampling.

EXAMPLE For a stable country (consistent political boundaries without immigration or emigration), a superpopulation could be the citizenry over the centuries. Thus, a decennial census in such a country could reflect an individual observation from its population size at a specific time.

NOTE 2 This definition is taken from ISO 3534-4:2014, 3.1.4.

A.2.1.3 Preparation of sampling frame (lists of the population)

The sampling frame (or lists of the population) refers to the complete collection of all of the individual parts into which a population is divided with their identification.

NOTE 1 A sampling frame provides an explicit representation of the population of interest for the study, generally consisting of a list. It is possible that the list can be incomplete or contain some errors. For example, an electoral register could contain individuals who have moved out of or into the voting district, contain individuals who are deceased since the construction of the sampling frame, could contain duplicate entries, or even contain convicted felons who are legally not entitled to vote and is to be expunged from the records.

EXAMPLE 1 Depending on the background information on the population, the sampling frame can be simple but explicit or, in the extreme case, highly complex. In a famous survey conducted in eastern India in 1940[28], the sampling frame is comprised of an enumeration of the fields, a list of villages, and a set of maps in different areas. From this heterogeneous material, a sampling frame was constructed and the study then proceeded.

EXAMPLE 2 In a multi-stage sampling project, the first stage could use provinces as the primary sampling units. In the second stage, the sampling units could be counties. In the third stage, the sampling units could be incorporated towns.

NOTE 2 This definition is taken from ISO 3534-4:2014, 3.1.25.

A.2.1.4 Cluster

Part of a population divided into mutually exclusive groups related in a certain manner.

NOTE 1 For economies of sampling, it can be much more efficient to sample collections of sampling units that constitute clusters. Cluster sampling is useful when the frame of sampling units is not available. Cluster sampling can also be an integral part of multi-stage sampling, where a first-level stage is given by towns, followed by a stage with apartment/condominium buildings as the next level cluster, and then finally specific floors/stages/levels of the building. At the lowest level stage, all sampling units are examined.

EXAMPLE In investigating medical insurance fraud (overpayment to the provider of medical services), it is easier to obtain a sample of patients and then examine all of their submitted claims than to consider the population of claims across many patients. Common examples of clusters include a household or residents in a given building, agricultural fields in villages, patients of medical practitioners, and students in classes in a school.

NOTE 2 This definition is taken from ISO 3534-4:2014, 3.1.6.

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