Expert Systems with Applications 36 (2009) 8789–8798

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

TQM measurement model for the biotechnology industry in Taiwan

Jui-Kuei Chen [a,1], I-Shuo Chen [b,*]

[a] Tamkang University, 4F, No. 20, Lane 22, WenZhou Street, Taipei City 10616, Taiwan
[b] National Chiao Tung University, 4F, No. 20, Lane 22, WenZhou Street, Taipei City 10616, Taiwan

ARTICLE INFO

Keywords:
Total quality management (TQM)
TQM measurement model
Biotechnology industry
Fuzzy analytic network process (FANP)

ABSTRACT

Due to the importance of the growth of biotechnology in Taiwan, the question of how the operation performance of the industry can be upgraded to sustain its competitive advantages has become an important question for Taiwanese biotechnology insiders. Recently, a growing number of organizations have implemented TQM in order to give them a competitive advantage [Chan, T. H., & Quazi, H. A. (2002). Overview of quality management practices in selected Asian countries. *Quality Management Journal, 9*(1), 172–180; Nilsson, L., Johnson, M. D., & Gustafsson, A. (2001). The impact of quality practices on customer satisfaction and business results: Product versus service organizations. *Journal of Quality Management, 6*, 5–27]. Meanwhile, quality related awards are also appearing for examining and identifying whether or not the overall quality of a firm is high. Each award, however, focuses only on examining certain items. It is impossible for a firm to make each examined item perfect. In addition to this, since the overall quality of the technology and products of some Taiwanese biotechnology corporations has been decreasing, the prestige of the Taiwanese biotechnology industry as a whole has decreased in the global market. Thus, in order to solve the above difficulties, this study attempts to find the most suitable measurement model for the biotechnology industry to enact quality improvement. The study first reviews a substantial body of literature on total quality management and categorizes measurement criteria. The study then proceeds with in-depth interviews with relevant background experts in order to extract and verify the most suitable measurement criteria. In addition to this, a FANP is utilized in order to analyze the weights of different measurement dimensions and criteria. The value of this study is its construction of a TQM measurement model for the Taiwanese biotechnology industry that can be used to improve its quality as well as to regain a higher market share of the global market.

1. Introduction

Industries have come to understand that, in order to stay competitive globally, a continuous improvement in organizational quality performance is a necessity (Mele & Colucio, 2006; Sitalakshmi, 2007). Thus, a body of organizations started to implement total quality management (TQM) in order to generate a competitive advantage (Chan & Quazi, 2002; Nilsson , Johnson, & Gustafsson, 2001). In Taiwan, the importance and growth of the biotechnology industry has, in recent years, increased dramatically; it is now Taiwan's second most profitable industry, the high-tech industry being the highest. Moreover, with the large amount of capital investment by the Taiwanese government, biotechnology related corporations are flourishing; nevertheless, due to the poor quality of products and technology from some of them, both the prestige and market share of Taiwanese biotechnology corporations are decreasing in the global market. In this regard, a precise and effective way to measure and operate quality improvement is necessary today.

Measuring overall quality is complex. A great number of quality awards exist, such as the European Quality Award, the Malcolm Baldrige National Quality Award, the Asia-Pacific Business Excellence Standard, the Vietnam Quality Award, QS 9000, and IS 9000 (Dinh, Barbara, & Tritos, 2006), all of which are trying to play a role in standardizing the overall quality of an organization. Each award, however, focuses on certain examined items. It is impossible for a firm to make each item perfect. Although the national quality award (NQA) is widely used in different industries in Taiwan, there is little evidence that it can improve a specific industry's overall quality, due to each industry's different features.

In light of this, a literature summarizing method is adapted in order to integrate related measurement criteria. A fuzzy analytic network process (FANP) was used to overcome the problem of dependence and feedback among dimensions or criteria. This is a general form of the FAHP that relieves hierarchical structural restrictions (Liou, Tzeng, & Chang, 2007). In this study, a literature summarizing method that is based on the NQA is utilized by combining it with FANP to create a new TQM measurement model.

---

[*] Corresponding author. Tel.: +886 911393602.
E-mail addresses: chen3362@ms15.hinet.net (J.-K. Chen), ch655244@yahoo.com.tw (I.-S. Chen).
[1] Tel.: +886 912272961.

0957-4174/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2008.11.013

2. Total quality management

The definition of quality, in the past, was the degree of conformance to a standard (Sitalakshmi, 2007). Sallis (1993) defined quality as that which best satisfies and exceeds customer needs and wants. Typically, quality has a variety of meanings (Sitalakshmi, 2007) and its range of meanings causes confusion as each individual's perception of quality differs (Shields, 1999). Since quality is proven to contribute to greater market share and return on investment (Cole, 1992; Philips, Chang, & Buzzell, 1983), lower manufacturing costs, improved productivity (Garvin, 1983) and improved strategic performance (Zhang, 2000), there are more and more organizations emphasizing the importance of increasing the quality of their service and products.

Within the field of quality improvement, total quality management (TQM) is the most referred as well as most used criterion for enhancing organizational quality (Chan & Quazi, 2002; Nilsson et al., 2001). Recent studies have defined TQM as an holistic management philosophy that strives for continuous organizational improvement (Kaynak, 2003). Furthermore, TQM can be seen as a management style based on producing quality service as defined by the customer, or based on achieving an organizational strategic imperative through continuous process improvement (Tseng, Lin, Chiu, & Liao, 2007). Additionally, TQM is also an integrated management philosophy aimed at continuously improving the performance of products, processes, and services in order to achieve and surpass customer expectations (Ozden & Birsen, 2006). To summarize the above literature, TQM can be defined as a managerial method both for improving an organization's core competitive ability and for gaining the maximization of market share within the industry in which it belongs.

There is a stream of recent literature showing that if a firm implements TQM, it will gain many advantages, such as helping companies to improve their performance (Chase, Jacobs, & Aquilano, 2006; Han, Chen, & Ebrahimpour, 2007; Knod & Schonberger, 2001; Wadsworth, Stephens, & Godfrey, 2002), reducing rework, a reduction in the costs related to poor quality (e.g., scrap, rework, late deliveries, warranty, replacement, etc.) (Antony, Leung, Knowles, & Gosh, 2002), and generating more unique competitive advantages (Reed, Lemak, & Mero, 2000). Hence, many quality related awards have arisen, such as the European Quality Award, the Malcolm Baldrige National Quality Award, the Asia-Pacific Business Excellent Standard, the Vietnam Quality Award, QS 9000, and IS 9000 (Dinh et al., 2006; Uzumeri, 1997). The purpose of each of these awards is to examine the performance of each firm's operating TQM. Each award, however, has its own examination items. It is difficult for a firm to focus on every item while trying to improve. Consequently, it is important for firms to be able to discover which criteria are most critical for them to engage.

3. Measurement criteria of TQM

The criteria for measuring TQM are various from one author to another (Ozden & Birsen, 2006). One of the early research works defining what constitutes TQM practice was conducted by Saraph et al. in 1989 (Joo & Yong, 2006). Since then, numerous related studies have been conducted by authors including Flynn, Schroeder, and Sakakibara (1994), Black and Porter (1996), Choi and Eboch (1998), Samson and Terziovski (1999) and Kaynak (2003). This study summarizes the different criteria proposed by related researchers in Table 1.

Based on the above literature, TQM criteria can be categorized into the following five dimensions: leaders, employees, customers, IT, and operating process. In Taiwan, the National Quality Award (NQA) is the most frequently utilized in some industries. It contains seven measurement dimensions: leadership and operation ideals, strategy management, the development of customers and a market, human resources and knowledge management, the applications and management of information strategy, process management, and operation performance. Because the measurement dimensions of NQA are similar to the above dimensions, the research structure in this study is based on NQA, with fixed

Table 1
Measurement criteria based on TQM.

Authors	TQM factors
Brah, Wong, and Rao (2000)	Top management support, customer focus, employee involvement, employee training, employee empowerment, supplier quality management, process improvement, service design, quality improvement rewards, benchmarking, and cleanliness and organization, customer satisfaction
Antony et al. (2002)	Management commitment, role of the quality department, training and education, employee involvement, continuous improvement, supplier partnership, product/service design, quality policies, quality data and reporting, communication to improve quality, and customer satisfaction orientation
Sila and Ebrahimpour (2002)	Top management commitment, employee involvement, employee empowerment, education and training, teamwork, customer focus, process management, information and analysis systems, strategic planning, open organization, a service culture, and especially process management
Shieh and Wu (2002)	Leadership, human resource management, process management, supply chain management and information management
Sureshchandar, Rajendran, and Anantharaman, (2002)	Top management commitment and visionary leadership, human resource management, technical systems, information and analysis systems, benchmarking, continuous improvement, customer focus, employee satisfaction, union intervention, social responsibility, services capes, and service culture
Besterfield (2003)	Quality culture, the quality chain, quality assurance, commitment to continuous improvement, and the support of top management
Prajogo and Sohal (2003)	Product innovation impacts the performance of total quality management
Jacqueline, Coyle, and Paula (2003)	Statistical process control, the commitment of top management, empowerment, and appropriate culture
Wanger and Schaltegger (2004)	Leadership
Escrig-Tena (2004) and Kenneth and Cynthia (2004)	Financial performance
Ozden and Birsen (2006)	Customer focus, continuous improvement, and teamwork
Nusrah, Ramayah, and Norizan (2006)	Employee empowerment, information and communication, customer focus, and continuous improvement
Ismail (2006)	Leadership, strategic planning, customer focus, information and analysis, human resource management, process management, supplier management, human resource results, customer results, and organizational effectiveness
Dinh et al., (2006)	Strategic planning
Keng, Nooh, Veeri, Lorraine, and Loke (2007)	Teamwork, reward and recognition, customer focus, organizational trust, extensive training, high level of communication, management commitment at all levels, employee involvement, empowerment and organizational culture
Han et al. (2007)	Supplier relationship, customer involvement, training, top management commitment, and product design

Table 2
Current status of biotechnology development in Taiwan (2005–2006).

Industry	Biotechnology (narrow)		Pharmaceutical		Medial devices		Total	
Year	2005	2006	2005	2006	2005	2006	2005	2006
Revenue	386	434	624	660	590	697	1,600	1,791
Number of companies	253	268	419	368	484	500	1,156	1,136
Size of work force (number)	8090	8570	14,995	12,224	15,000	16,350	38,085	37,144
Export value[a]	153	176	115	137	270	293	538	606
Import value[a]	161	187	577	698	395	447	1133	1332
Domestic sales vs. export	60:40	60:40	82:18	79:21	54:46	58:42	66:34	66:34
Domestic market demand[a]	394	445	1086	1221	715	851	2195	2517

Source: Development Center for Biotechnology, Taiwan Institute of Economic Research, Biotechnology and Pharmaceutical Industries Program Office, MOEA, 2007.
[a] Units: NT$100 million.

criteria chosen using in-depth interviews and referring to the above summarized literature. Furthermore, in accordance with related expert opinions, the sample industry of this study focuses mainly on research and development; therefore, the study finally concludes a measurement dimension, R&D and innovation, to be the base for developing measurement criteria.

4. The biotechnology industry in Taiwan

4.1. Definition and the technology range of the biotechnology industry

According to the Taiwanese Biotechnology and Pharmaceutical Industries Program Office's report (2007), Biotechnology is an integrated science of a multi-research field. It can be seen as a basic tool in researching life science, medical science, and agronomy. Biotechnology consists of the science of using biological processes and technology to both solve problems and produce useful products, where examples include utilizing the characteristics or ingredients of microorganisms, vegetation, or animals to produce products; applying the design of products that enter molecules in order to understand life phenomena; and developing the technological platform to solve the above problems. The overall goal of these efforts is to improve the quality of life of human beings. Therefore, biotechnology includes traditional biotechnology (e.g., microorganism fermentation), modern biotechnology (e.g., bioengineering), and new biotechnology (e.g., the integration of hybrid high technology and life science). Moreover, in Taiwan, in order to promote the domestic biotechnology industry, biotechnology related medical industries such as the pharmaceutical industry, the medical device industry, the agriculture and food industry, the biologic resource industry, and the service industry that contains the medical and R&D service industries are included in the field of biotechnology industry. Therefore, in Taiwan, the technology range of biotechnology industry can be formally categorized into three dimensions: first, the biotechnology industry (i.e., unique biochemistry, biomedical, agriculture, and environmental manufacturing and service), also called the narrow biotechnology industry, the pharmaceutical industry, and the medical devices industry.

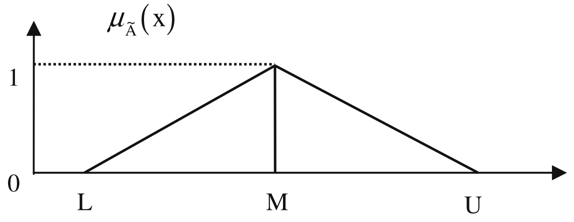

Fig. 1. A triangular fuzzy number.

4.2. Recent status on biotechnology industry

In accordance with the latest survey of the Development Center for Biotechnology (2007), the biotechnology industry in Taiwan formally includes biotechnology, pharmaceuticals and medical devices. In 2006, the total annual revenue for these industries in Taiwan was nearly NT$179.1 billion, of which NT$43.4 billion came from biotechnology, with 434 companies. The scope of businesses covered included genomics, drugs, diagnostics, agricultural biotechnology, environmental biotechnology, protein drugs, contract research organizations, biochips and bioinformatics.

The island's pharmaceutical industry returned NT$66.0 billion with 368 companies active in this sector. The medical devices industry returned NT$69.7 billion coming from 397 companies. The biotechnology workforce size is 37,144, of which 8570 are in the biotechnology industry, 12,224 in the pharmaceutical industry and 16,350 in the medical devices industry. To present the growth of the biotechnology industry in Taiwan, the current status is provided in Table 2.

Due to both the importance of the growth of the biotechnology and the large capital investment from the Taiwanese government, biotechnology related corporations are growing quickly; nonetheless, since some of these corporations produce products of inferior quality, both the prestige and global market share of Taiwanese companies are shrinking. In this regard, knowing the most precise and effective way to measure and operate quality improvement is extremely important. This study, by utilizing both the literature and the opinions of experts, aims to arrive at an effective way for these corporations to conduct quality improvement.

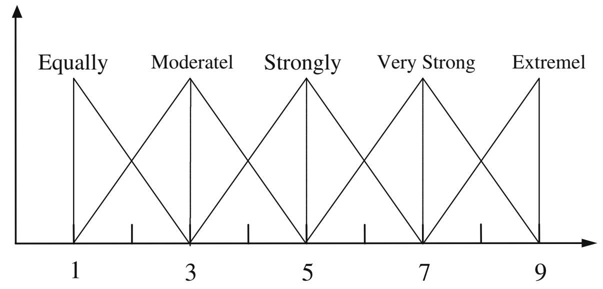

Fig. 2. Fuzzy memberships function for linguistic values for attributes.

Table 3
Definition and membership function of fuzzy numbers.

Fuzzy number	Linguistic variable	Triangular fuzzy number
$\tilde{9}$	Extremely important/preferred	(7,9,9)
$\tilde{7}$	Very strongly important/preferred	(5,7,9)
$\tilde{5}$	Strongly important/preferred	(3,5,7)
$\tilde{3}$	Moderately important/preferred	(1,3,5)
$\tilde{1}$	Equally important/preferred	(1,1,3)

5. Fuzzy analytic network process

5.1. Analytic hierarchy process

Analytic hierarchy process (AHP) was developed by Thomas L. Saaty in 1971. The AHP method is known as an eigenvector method. It indicates that the eigenvector corresponding to the largest eigenvalue of the pairwise comparisons matrix gives the relative priorities of the factors, and it preserves ordinal preferences among the alternatives. This means that if an alternative is preferred to another, its eigenvector component is larger than that of the other. A vector of weights obtained from the pairwise comparisons matrix reflects the relative performance of the various factors.

A growing literature now argues, however, that AHP has its drawbacks. Studies have concluded that AHP can be applied to specific, but not fuzzy decision making, that AHP evaluates questions using different criteria for different parts of the test set, that AHP cannot include uncertainty factors of people toward objects, and that the priority of AHP is unspecific. Furthermore, AHP is based on the concept of independence among each factor; however, this does not fit real environments. Thus, the study employed a modified form of AHP, called fuzzy ANP (FANP), in order to arrive at more precise results.

5.2. Fuzzy set theory

Fuzzy set theory was first developed in 1965 when Professor L.A. Zadeh was trying to solve fuzzy phenomenon problems that exist in the real world, such as uncertain, incomplete, nonspecific, and fuzzy situations. Fuzzy set theory has an advantage over traditional set theory in describing set concepts in human language. It demonstrates specific and fuzzy characteristics in language on the evaluation, and it uses a membership function concept to represent the field in which a fuzzy set can permit a situation such as “incompletely belongs to” and “incompletely does not belong to”.

5.3. Fuzzy number

We order the Universe of Discourse such that U is a whole target, and each target in the Universe of Discourse is called an element. Fuzzy $\tilde{A}$ states for U that random $x \to U$, appointing a real number $\mu_{\tilde{A}}(x) \to [0,1]$. We call anything above that level of x *under A*.

The set of real numbers R is a triangular fuzzy number (TFN): $\tilde{A}$, which means that $x \in R$, appointing $\mu_{\tilde{A}}(x) \in [0,1]$, and

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-L)/(M-L), & L \le x \le M, \\ (U-x)/(U-M), & M \le x \le U, \\ 0, & \text{otherwise}, \end{cases}$$

The triangular fuzzy number above can be written as $\tilde{A} = (L, M, U)$, where L and U represent the fuzzy probability between the lower and upper boundaries of evaluation information, as shown in Fig. 1. Assume two fuzzy numbers $\tilde{A_1} = (L_1, M_1, U_1)$ and $\tilde{A_2} = (L_2, M_2, U_2)$:

(1) $\tilde{A_1} \oplus \tilde{A_2} = (L_1, M_1, U_1) \oplus (L_2, M_2, U_2) = (L_1 + L_2, M_1 + M_2, U_1 + U_2)$.
(2) $\tilde{A_1} \otimes \tilde{A_2} = (L_1, M_1, U_1) \otimes (L_2, M_2, U_2) = (L_1 L_2, M_1 M_2, U_1 U_2)$, $L_i > 0, M_i > 0, U_i > 0$.
(3) $\tilde{A_1} - \tilde{A_2} = (L_1, M_1, U_1) - (L_2, M_2, U_2) = (L_1 - L_2, M_1 - M_2, U_1 - U_2)$.
(4) $\tilde{A_1} \div \tilde{A_2} = (L_1, M_1, U_1) \div (L_2, M_2, U_2) = (L_1/U_2, M_1/M_2, U_1/L_2)$. $L_i > 0, M_i > 0, U_i > 0$.

$$\tilde{A}_1^{-1} = (L_1, M_1, U_1)^{-1} = (1/U_1, 1/M_1, 1/L_1), \quad L_i > 0,\ M_i > 0,\ U_i > 0.$$

5.4. The fuzzy linguistic variable

The fuzzy linguistic variable is a variable that reflects the different levels of human language. Its value represents the range from natural to artificial language. When precisely reflecting the value or meaning of a linguistic variable, there must be an appropriate way for the variable to change. Variables representing a human word or sentence can be divided into numerous linguistic criteria, such as equally important, moderately important, strongly important, very strongly important, and extremely important, as shown in Fig. 2; the definitions and descriptions of these terms are given in Table 3. For the purpose of the present study, the five criteria above (i.e., equally important, moderately important, strongly important, very strongly important and extremely important) are used.

5.5. Analytic network process (ANP)

The purpose of the ANP approach is to solve the problem of interdependence and feedback between criteria and alternatives. The ANP is the general form of the analytic hierarchy process (AHP), which has been used in multicriteria decision making (MCDM) to release the restriction of hierarchical structure. Furthermore, it has been applied to project selection, product planning, strategic decision making, optimal scheduling, etc. (Huang, Tzeng, & Ong, 2005).

The first phase of the ANP is comparing the measurement criteria of the overall system to form the super matrix. This step can be accomplished through pairwise comparisons. The relative importance value of pairwise comparisons can be assigned on a scale of 1–9, representing equal importance to extreme importance (Saaty, 1980). The following shows the general form of the super matrix:

$$W = \begin{array}{cc} & \begin{array}{cccccccccc} & C_1 & & & C_2 & & \cdots & & C_m & \\ e_{11} & \cdots & e_{1n_1} & e_{21} & \cdots & e_{2n_2} & \cdots & e_{m1} & \cdots & e_{mn_m} \end{array} \\ \begin{array}{cc} & e_{11} \\ & e_{12} \\ C_1 & \vdots \\ & e_{1n_1} \\ & e_{21} \\ & e_{22} \\ C_2 & \vdots \\ & e_{2n_2} \\ \vdots & \vdots \\ & e_{m1} \\ & e_{m2} \\ C_m & \vdots \\ & e_{mn_m} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mn} \end{bmatrix} \end{array}$$

where C_m denotes the mth cluster, e_{mn} denotes the nth element in the mth cluster, and W_{ij} is the principal eigenvector influencing the elements compared in the jth cluster to the nth cluster. In addition, if the jth cluster has no influence on the nth cluster, then $W_{ij} = 0$.

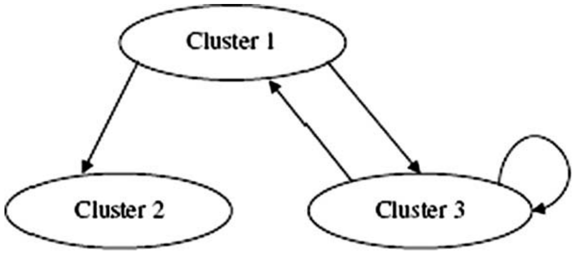

Fig. 3. Case 1 structure.

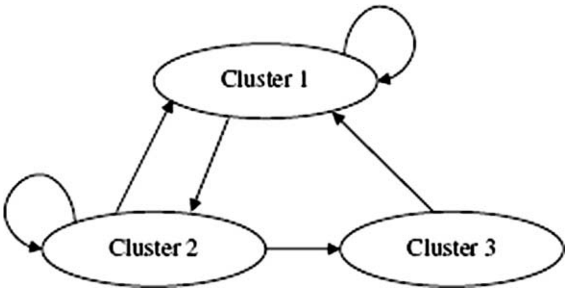

Fig. 4. Case 2 structure.

Based on the above, the form of the super matrix relies on the variety of the structure. Several structures were proposed by Saaty, including hierarchy, holarchy, suparchy, intarchy, etc. (Huang et al., 2005). In order to demonstrate how the structure is affected by the super matrix, Huang et al. (2005) offer two simple cases that both have three clusters to show how to form the super matrix in accordance with the structures (Fig. 3).

Based on Fig. 3, we can form the super matrix as follows:

$$W = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 0 & 0 & W_{13} \\ W_{21} & 0 & 0 \\ W_{31} & 0 & W_{33} \end{bmatrix} \end{array}$$

In Fig. 4, the second case is more complex than the first one. From Fig. 4, we can form the super matrix as follows:

$$W = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} W_{11} & W_{12} & W_{13} \\ W_{21} & W_{22} & 0 \\ 0 & W_{32} & 0 \end{bmatrix} \end{array}$$

When the super matrix has been formed, the weighted super matrix can then be derived by transforming all columns so that they sum exactly to unity (Huang et al., 2005). This step is similar

Table 4
Research structure of this study.

Goal	Evaluation dimensions	Evaluation criteria
Biotechnology industry KSF exploration based on TQM	Leadership and operation ideals (D1)	Operational values and ideals restructure (C1)
		Organizational quality improving mission (C2)
		Top managers' leading style (C3)
		TQM culture construction (C4)
		The increasing of social contribution (C5)
	Strategy management (D2)	Organization of operation strategy planning (C6)
		Operation structure adjustment (C7)
		The quality improvement of strategy (C8)
	R&D and innovation (D3)	Process redefinition of R&D and innovation (C9)
		Input of R&D and innovation (C10)
		Evaluation of R&D and innovation results (C11)
	The development of customers and a market (D4)	Market operation strategy development (C12)
		Business relation management (C13)
		Customer relationship management (C14)
	Human resource and knowledge management (D5)	Human resource planning (C15)
		Human resource development (C16)
		Human resources utilization (C17)
		Employee relationship management (C18)
		Knowledge management (C19)
	The application and management of information strategy (D6)	Biotechnology information receiving channel (C20)
		Internet applications (C21)
		Biotechnology information utilization (C22)
	Process management (D7)	Manufacturing process management (C23)
		Supportive activity planning (C24)
		Cross-unit (Department) Management (C25)
	Operation performance (D8)	Customer satisfaction (C26)
		Market enlargement performance (C27)
		Financial performance (C28)
		Human resource development performance (C29)
		Information management performance (C30)
		Process management performance (C31)
		Unique competitive ability gaining performance (C32)
		Prestige measurement (C33)

Table 5
Pairwise comparison matrix and weights of measurement dimension.

Measurement dimension	Local weight	Inner dependence weight								Interdependence weight
D1	0.063		0.079	0.042	0.046	0.045	0.050	0.036	0.065	0.0548
D2	0.036	0.064		0.080	0.089	0.053	0.062	0.043	0.089	0.0535
D3	0.243	0.228	0.238		0.312	0.315	0.290	0.306	0.363	0.2378
D4	0.183	0.213	0.192	0.271		0.099	0.140	0.150	0.234	0.1725
D5	0.119	0.063	0.076	0.099	0.057		0.081	0.060	0.075	0.0936
D6	0.156	0.107	0.090	0.090	0.083	0.135		0.063	0.139	0.1214
D7	0.053	0.037	0.031	0.041	0.041	0.055	0.025		0.036	0.0446
D8	0.147	0.288	0.294	0.377	0.371	0.299	0.352	0.342		0.2219

Table 6
Pairwise comparison matrix and weights of D1 criteria.

Measurement criteria 1	C1			C2			C3			C4			C5			Local weight	Global weight
C1	1.000	1.000	3.000	0.554	0.629	0.905	0.212	0.252	0.378	0.201	0.231	0.315	4.395	6.795	7.825	0.126	0.0069
C2	1.104	1.591	1.806	1.000	1.000	3.000	0.135	0.160	0.273	0.353	0.481	0.713	4.395	5.658	7.187	0.155	0.0085
C3	2.646	3.974	4.711	3.659	6.240	7.399	1.000	1.000	3.000	1.403	2.080	2.836	1.685	2.265	3.000	0.408	0.0224
C4	3.177	4.327	4.983	1.403	2.080	2.836	0.353	0.481	0.713	1.000	1.000	3.000	1.383	2.107	2.720	0.251	0.0138
C5	0.128	0.147	0.228	0.139	0.177	0.228	0.333	0.442	0.594	0.368	0.475	0.723	1.000	1.000	3.000	0.060	0.0033

Table 7
Pairwise comparison matrix and weights of D2 criteria.

Measurement criteria 2	C6			C7			C8			Local weight	Global weight
C6	1.000	1.000	3.000	1.834	3.000	3.709	0.244	0.289	0.417	0.2789	0.0149
C7	0.270	0.333	0.545	1.000	1.000	3.000	0.353	0.481	0.713	0.1701	0.0091
C8	2.399	3.455	4.091	1.403	2.080	2.836	1.000	1.000	3.000	0.5510	0.0295

Table 8
Pairwise comparison matrix and weights of D3 criteria.

Measurement criteria 3	C9			C10			C11			Local weight	Global weight
C9	1.000	1.000	3.000	1.326	1.910	2.362	0.255	0.306	0.454	0.2279	0.0542
C10	0.423	0.523	0.754	1.000	1.000	3.000	0.177	0.231	0.357	0.1406	0.0335
C11	2.203	3.267	3.923	2.798	4.327	5.658	1.000	1.000	3.000	0.6314	0.1502

Table 9
Pairwise comparison matrix and weights of D4 criteria.

Measurement criteria 4	C12			C13			C14			Local weight	Global weight
C12	1.000	1.000	3.000	0.353	0.481	0.713	0.177	0.231	0.357	0.1348	0.0232
C13	1.403	2.080	2.836	1.000	1.000	3.000	0.231	0.333	0.467	0.2373	0.0409
C14	2.798	4.327	5.658	2.140	3.000	4.327	1.000	1.000	3.000	0.6280	0.1083

Table 10
Pairwise comparison matrix and weights of D5 criteria.

Measurement criteria 5	C15			C16			C17			C18			C19			Local weight	Global weight
C15	1.000	1.000	3.000	2.140	3.000	4.327	0.121	0.135	0.189	0.201	0.231	0.315	0.167	0.212	0.298	0.0685	0.0064
C16	0.231	0.333	0.467	1.000	1.000	3.000	0.167	0.212	0.298	0.128	0.147	0.228	0.167	0.212	0.298	0.0444	0.0042
C17	5.278	7.399	8.277	3.361	4.711	5.984	1.000	1.000	3.000	0.400	0.481	0.628	0.160	0.201	0.273	0.1807	0.0169
C18	3.177	4.327	4.983	4.395	6.795	7.825	1.593	2.080	2.498	1.000	1.000	3.000	0.255	0.306	0.454	0.2520	0.0236
C19	3.361	4.711	5.984	3.361	4.711	5.984	3.659	4.983	6.240	2.203	3.267	3.923	1.000	1.000	3.000	0.4544	0.0425

Table 11
Pairwise comparison matrix and weights of D6 criteria.

Measurement criteria 6	C20			C21			C22			Local weight	Global weight
C20	1.000	1.000	3.000	2.646	3.309	4.327	0.160	0.167	0.251	0.2197	0.0267
C21	0.231	0.302	0.378	1.000	1.000	3.000	0.231	0.278	0.429	0.1158	0.0141
C22	3.984	5.984	6.240	2.330	3.603	4.327	1.000	1.000	3.000	0.6645	0.0807

Table 12
Pairwise comparison matrix and weights of D7 criteria.

Measurement criteria 7	C23			C24			C25			Local weight	Global weight
C23	1.000	1.000	3.000	4.395	5.658	7.187	0.192	0.219	0.289	0.2573	0.0115
C24	0.139	0.177	0.228	1.000	1.000	3.000	0.160	0.167	0.251	0.0765	0.0034
C25	3.460	4.576	5.196	3.984	5.984	6.240	1.000	1.000	3.000	0.6662	0.0297

Table 13
Pairwise comparison matrix and weights of D8 criteria.

Measurement criteria 8	C26			C27			C28			C29			C30			C31			C32			C33			Local weight	Global weight
C26	1.000	1.000	3.000	0.231	0.278	0.429	0.128	0.147	0.228	1.272	1.806	2.169	2.646	3.974	4.711	2.537	3.757	4.327	0.167	0.212	0.298	2.140	3.000	4.327	0.0819	0.0182
C27	2.330	3.603	4.327	1.000	1.000	3.000	0.167	0.177	0.273	3.659	6.240	7.399	2.646	4.149	5.658	4.395	6.795	7.825	0.302	0.400	0.545	3.659	5.196	6.795	0.1646	0.0365
C28	4.395	6.795	7.825	3.659	5.658	5.984	1.000	1.000	3.000	3.659	6.240	7.399	3.460	5.984	7.399	2.798	4.327	5.658	0.302	0.400	0.545	4.395	5.658	7.187	0.2650	0.0588
C29	0.461	0.554	0.786	0.135	0.160	0.273	0.135	0.160	0.273	1.000	1.000	3.000	0.333	0.368	0.545	2.646	3.309	4.327	0.123	0.139	0.209	2.646	3.974	4.711	0.0506	0.0112
C30	0.212	0.252	0.378	0.177	0.241	0.378	0.135	0.167	0.289	1.834	2.720	3.000	1.000	1.000	3.000	1.403	2.080	2.836	0.128	0.147	0.228	3.177	4.327	4.983	0.0580	0.0129
C31	0.231	0.266	0.394	0.128	0.147	0.228	0.177	0.231	0.357	0.231	0.302	0.378	0.353	0.481	0.713	1.000	1.000	3.000	0.123	0.139	0.209	3.177	4.327	4.983	0.0363	0.0081
C32	3.361	4.711	5.984	1.834	2.498	3.309	1.834	2.498	3.309	4.785	7.187	8.160	4.395	6.795	7.825	4.785	7.187	8.160	1.000	1.000	3.000	4.395	5.658	7.187	0.3202	0.0710
C33	0.231	0.333	0.467	0.147	0.192	0.273	0.139	0.177	0.228	0.212	0.252	0.378	0.201	0.231	0.315	0.201	0.231	0.315	0.139	0.177	0.228	1.000	1.000	3.000	0.0234	0.0052

to the Markov chain concept for ensuring that the sum of the probabilities of all states equals one. Then, we limit the power of the weighted super matrix by using Eq. (1) to get the global weights:

$$\lim_{k\to\infty} \mathbf{W}^k. \tag{1}$$

In this step, if the super matrix is cyclic, then more than one limiting super matrix exists. More precisely, there are two or more limiting super matrices in this case, and the Cesaro sum would be calculated to determine which matrix has priority. The Cesaro sum is formulated as Eq. (2)

$$\lim_{k\to\infty} \left(\frac{1}{N}\right) \sum_{k=1}^{N} \mathbf{W}^k \tag{2}$$

to calculate the average effect of the limiting super matrix, or the super matrix could be raised to large powers to get the priority weights.

From the above description of the ANP approach, the most critical advantage of this analysis is that, first, that it is appropriate for both quantitative and qualitative data types; and second, that it can solve the problem of interdependence and feedback between whole factors. Due to these two reasons, the ANP approach is adopted by this study.

5.6. Steps of fuzzy analytic network process calculation

Summarizing the above literature, the steps of fuzzy ANP calculation in this study are provided as follows:

Step 1: Confirm both the dimensions and criteria of the model.
Step 2: Hierarchically build up an ANP model containing goals, dimensions, and criteria.
Step 3: Determine the local weights of both dimensions and criteria by utilizing pairwise comparison matrices (assuming that there is no interdependence among the criteria). The relative importance value of pairwise comparisons is provided in Table 2.
Step 4: Determine the inner dependence matrix of each dimension with respect to the other dimensions. In step 3, the dependence of the local weights of the dimensions of the inner matrix has already been found. This next step is to calculate the interdependent weights of the dimensions.
Step 5: Calculate the global weights for the criteria. These can be acquired by multiplying the local weight of the criteria with the interdependent dimension weights above each.

6. Empirical study of TQM measurement model

The TQM measurement model for the biotechnology industry is a hybrid composition; furthermore, it is obvious that the criteria explored must be context dependent and in accord with real situations. Before sending out questionnaires, five senior biotechnology industry background experts were consulted, and recent research studies and national quality awards (NQA) were referred to in order to construct eight dimensions (Leadership and Operation Ideals, Strategy Management, R&D and Innovation, The Development of Customers and a Market, Human Resource and Knowledge Management, The Application and Management of Information Strategy, Process Management, and Operation Performance) with each dimension having three to eight criteria. A questionnaire was used to find out from seven groups comprising 31 experts – 10 from the narrow biotechnology industry, 11 from pharmaceutical industry, and 10 from medial devices industry – their ranking of each dimension and criterion with respect to the

Table 14
The new TQM measurement model.

Goal	Measurement dimension	Measurement criteria
TQM achievement for Taiwanese biotechnology industry	Market focus Organization focus Process focus Result focus	Customer relationship management sustention and reinforce Unique competitive ability development Information utilization maximization Financial evaluation and improvement R&D and innovation productivity evaluation and developing

Table 15
The fuzzy ANP results of the study.

Goal	Evaluation dimensions	Global weight	Ranking	Evaluation criteria	Local weight	Global weight	Ranking
Biotechnology industry KSF exploration based on TQM	Leadership and operation ideals (D1)	0.0548	7	Operational values and ideals restructure (C1)	0.126	0.0069	28
				Organizational quality improving mission (C2)	0.155	0.0085	26
				Top managers' leading style (C3)	0.408	0.0224	16
				TQM culture construction (C4)	0.251	0.0138	21
				The increasing of social contribution (C5)	0.060	0.0033	33
	Strategy management (D2)	0.0535	8	Organization of operation strategy planning (C6)	0.2789	0.0149	19
				Operation structure adjustment (C7)	0.1701	0.0091	25
				The quality improvement of strategy (C8)	0.5510	0.0295	12
	R&D and innovation (D3)	0.2378	1	Process redefinition of R&D and innovation (C9)	0.2279	0.0542	6
				Input of R&D and innovation (C10)	0.1406	0.0335	10
				Evaluation of R&D and innovation results (C11)	0.6314	0.1502	1
	The development of customers and a market (D4)	0.1725	3	Market operation strategy development (C12)	0.1348	0.0232	15
				Business relation management (C13)	0.2373	0.0409	8
				Customer relationship management (C14)	0.6280	0.1083	2
	Human resource and knowledge management (D5)	0.0936	5	Human resource planning (C15)	0.0685	0.0064	29
				Human resource development (C16)	0.0444	0.0042	31
				Human resources utilization (C17)	0.1807	0.0169	18
				Employee relationship management (C18)	0.2520	0.0236	14
				Knowledge management (C19)	0.4544	0.0425	7
	The application and management of information strategy (D6)	0.1214	4	Biotechnology information receiving channel (C20)	0.2197	0.0267	13
				Internet applications (C21)	0.1158	0.0141	20
				Biotechnology information utilization (C22)	0.6645	0.0807	3
	Process management (D7)	0.0446	6	Manufacturing process management (C23)	0.2573	0.0115	23
				Supportive activity planning (C24)	0.0765	0.0034	32
				Cross-unit (Department) management (C25)	0.6662	0.0297	11
	Operation performance (D8)	0.2219	2	Customer satisfaction (C26)	0.0819	0.0182	17
				Market enlargement performance (C27)	0.1646	0.0365	9
				Financial performance (C28)	0.2650	0.0588	5
				Human resource development performance (C29)	0.0506	0.0112	24
				Information management performance (C30)	0.0580	0.0129	22
				Process management performance (C31)	0.0363	0.0081	27
				Unique competitive ability gaining performance (C32)	0.3202	0.0710	4
				Prestige measurement (C33)	0.0234	0.0052	30

TQM measurement, utilizing a 5-point scale ranging from 9 (extremely important) to 1 (no effect) as Table 3 shows. The top five criteria from each dimension were chosen to construct the final model for measuring TQM of the biotechnology industry (as Table 4).

After forming the TQM measurement model, local weights of the dimensions and criteria which were in the second and third levels of the TQM measurement model were calculated first. All of the fuzzy measurement matrices were developed in the same way. Additionally, pairwise comparison matrices and local weights were analyzed. The local weights for the dimensions were calculated in a similar way to the fuzzy measurement matrices (given in the second column of Table 5). Then, inner dependence weights of the dimensions were calculated next and the dependencies among the dimensions were considered. The resulting inner dependence weights are given in the third to tenth columns of Table 5.

Next, using the computed inner dependence weights above, interdependent weights of the dimensions were computed by timing the inner dependence weights matrix of the dimensions with the local weights of dimensions. The result is given in the last column of Table 5.

Using the interdependent weights of each dimension and local weights of criteria, global weights for the criteria were subsequently calculated. Global criteria weights were computed by timing the local weight of the criteria (given in the last second column of Tables 6–13), with the interdependent weights of the dimensions to which it belongs. All global weights are provided in the last column of Tables 6–13. Based on the global weights calculated above, the top five critical criteria that can significantly improve the overall quality performance of the biotechnology industry are “Evaluation of R&D and Innovation Results”, “Customer Relationship Management”, “Biotechnology Information Utilization”, “Unique Competitive Ability Gaining Performance”, and “Financial Performance”.

After in-depth interviews with experts from three different dimensions of the biotechnology industry in Taiwan, the study found that the most effective measurement (helpful) criteria in improving quality performance can be re-categorized into four focus dimensions: market focus (customer relationship management sustention and reinforce), organization focus (unique competitive ability development), process focus (information utilization), and result focus (R&d and innovation productivity evaluation and developing and financial evaluation and improvement). Hence, biotechnology corporations that are devoted to improving their quality more efficiently and precisely should utilize these four “focuses”. The study proposes the final TQM measurement model as given in Table 14 and summarizes the result with rankings as given in Table 15.

7. Conclusion

Because of the increasing emphasis on the biotechnology industry in Taiwan, the government has invested a great amount of capital in order to turn it into one of the most profitable Taiwanese industries of the future. There is, consequently, a growing body of studies on such corporations over the past few years. Recently, however, the poor quality of some of those corporations has resulted in dangerous products and decreased the prestige of these corporations around the world. Upgrading the quality of the biotechnology industry is necessary for Taiwan if it is to reclaim prestige and market share in the global market. In the past, the national quality award has been the most useful tool for tackling different kinds of industries. Due to different characteristics between each industry, however, it is necessary for Taiwan’s newest profitable industry to construct a suitable quality measuring model for assessments. Based on several quality measurement criteria proposed by numerous researchers, we utilized in-depth interviews and FANP to develop a TQM measurement model that considers interdependence between a range of dimensions and criteria and their weighting. The study, reflecting on the results, proposes a new TQM measurement model for the Taiwanese biotechnology industry.

References

Antony, J., Leung, K., Knowles, G., & Gosh, S. (2002). Critical success factors of TQM implementation in Hong Kong industries. *International Journal of Quality and Reliability Management, 19*(5), 551–566.

Besterfield, D. (2003). *Quality control* (7th ed). NY: Prentice Hall.

Biotechnology and Pharmaceutical Industries Program Office (2007). Development center for biotechnology, Taiwan institute of economic research, biotechnology and pharmaceutical industries program office. <http://www.biopharm.org.tw/2t2s/situation.html>, MOEA Retrieved 09.05.08.

Black, S. A., & Porter, L. J. (1996). Identification of critical factors of TQM. *Decision Sciences, 27*(1), 1–21.

Brah, S. A., Wong, J. L., & Rao, B. M. (2000). TQM and business performance in the service sector: A Singapore study. *International Journal of Operations and Production Management, 20*(11), 1293–1312.

Chan, T. H., & Quazi, H. A. (2002). Overview of quality management practices in selected Asian countries. *Quality Management Journal, 9*(1), 172–180.

Chase, R. B., Jacobs, F. R., & Aquilano, N. J. (2006). *Operations management for competitive advantage* (11th ed). NY: McGraw-Hill.

Choi, T., & Eboch, K. (1998). The TQM paradox: Relations among TQM practices, plant performance, and customer satisfaction. *Journal of Operations Management, 17*(1), 59–75.

Cole, R. E. (1992). The quality revolution. *Production and Operations Management, 1*(1), 118–220.

Dinh, T. H., Barbara, I., & Tritos, L. (2006). The impact of total quality management on innovation findings from a developing country. *International Journal of Quality and Reliability, 23*(9), 1092–1117.

Escrig-Tena, A. B. (2004). TQM as a competitive factor: A theoretical and empirical analysis. *International Journal of Quality and Reliability Management, 21*(6), 612–637.

Flynn, B. B., Schroeder, R. G., & Sakakibara, S. (1994). A framework for quality management research and an associated measurement instrument. *Journal of Operations Management, 11*, 339–366.

Garvin, D. A. (1983). Quality on the line. *Harvard Business Review, 61*, 64–75.

Han, S. B., Chen, S. K., & Ebrahimpour, B. (2007). The impact of ISO 9000 on TQM and business performance. *Journal of Business and Economic Studies, 13*(2), 1–21.

Ismail, S. (2006). Examining the effects of contextual factors on TQM and performance through the lens of organizational theories: An empirical study. *Journal of Operations Management, 25*, 83–109.

Jacqueline, A. M., Coyle, S., & Paula, C. M. (2003). The role of individual differences in employee adoption of TQM orientation. *Journal of Vocational Behavior, 62*, 320–340.

Joo, Y. J., & Yong, J. W. (2006). Relationship between total quality management (TQM) and continuous improvement of international project management (CIIPM). *Technovation, 26*, 716–722.

Kaynak, H. (2003). The relationship between total quality management practices and their effects on firm performance. *Journal of Operations Management, 21*, 405–435.

Keng, B. O., Nooh, A. B., Veeri, A., Lorraine, V., & Loke, A. K. Y. (2007). Does TQM influence employees’ job satisfaction: An empirical case analysis? *International Journal of Quality and Reliability Management, 24*(1), 62–77.

Kenneth, M. Y., & Cynthia, E. M. (2004). Causation or covariation: An empirical re-examination of the link between TQM and financial performance. *Journal of Operations Management, 22*, 291–311.

Knod, E. M., Jr., & Schonberger, R. J. (2001). *Operations management: Meeting customer’s demands* (7th ed). NY: McGraw-Hill.

Liou, J. H., Tzeng, G. H., & Chang, H. C. (2007). Airline safety measurement using a novel hybrid model. *Journal of Air Transport Management, 13*(4), 243–249.

Mele, C., & Colucio, M. (2006). The evolving path of TQM: Towards business excellence and stakeholder value. *International Journal of Quality and Reliability Management, 23*(5), 464–489.

Nilsson, L., Johnson, M. D., & Gustafsson, A. (2001). The impact of quality practices on customer satisfaction and business results: Product versus service organizations. *Journal of Quality Management, 6*, 5–27.

Nusrah, S., Ramayah, T., & Norizan, M. S. (2006). TQM practices, service quality, and market orientation: Some empirical evidence from a developing country. *Management Research News, 29*(11), 713–728.

Huang, J. J., Tzeng, G. H., & Ong, C. S. (2005). Multidimensional data in multidimensional scaling using the analytic network process. *Pattern Recognition Letters, 26*(6), 755–767.

Ozden, B., & Birsen, K. (2006). An analytical network process-based framework for successful total quality management (TQM): An assessment of Turkish manufacturing industry readiness. *International Journal of Production Economics, 105*, 79–96.

Philips, L. W., Chang, D. R., & Buzzell, R. D. (1983). Product quality, cost position business performance. A test of some key hypotheses. *Journal of Marketing, 46*, 26–43.

Prajogo, D. I., & Sohal, A. S. (2003). The relationship between TQM practices, quality performance, and innovation performance. An empirical examination. *International Journal of Quality and Reliability Management, 20*(8), 901–918.

Reed, R., Lemak, D. J., & Mero, N. P. (2000). Total quality management and sustainable competitive advantage. *Journal of Quality Management, 5*, 5–26.

Saaty, J. T. (1980). *The analytic hierarchy process*. Columbus: McGraw-Hill.

Sallis, E. (1993). *Total quality management in education*. London: Kogan Page.

Samson, D., & Terziovski, M. (1999). The relationship between total quality management practices and operational performance. *Journal of Operations Management, 17*, 393–409.

Shieh, H. M., & Wu, K. Y. (2002). The relationship between total quality management and project performance in building planning phase: An empirical study of real estate industries in Taiwan. *Total Quality Management, 13*(1), 133–151.

Shields, P. M. (1999). Zen and the art of higher education maintenance: Bridging classic and romantic notions of quality. *Journal of Higher Education Policy and Management, 21*(2), 165–172.

Sila, I., & Ebrahimpour, M. (2002). An investigation of the total quality management survey based research published between 1989 and 2000: A literature review. *International Journal of Quality and Reliability Management, 19*(7), 902–970.

Sitalakshmi, V. (2007). A framework for implementing TQM in higher education programs. *Quality Assurance in Education, 15*(1), 92–112.

Sureshchandar, G. S., Rajendran, C., & Anantharaman, R. N. (2002). The relationship between management's perception of total quality service and customer perceptions of service quality. *Total Quality Management, 13*(1), 69–88.

Tseng, M. L., Lin, Y. H., Chiu, S. F., & Liao, C. H. (2007). A structural equation model of total quality management and cleaner production implementation. *The Journal of American Academy of Business, 11*(1), 65–71.

Uzumeri, M. V. (1997). ISO 9000 and other metastandards: Principles for management practice? *Academy of Management Executive, 11*(1), 21–36.

Wadsworth, H. M., Stephens, K. S., & Godfrey, A. B. (2002). *Modern methods for quality control and improvement* (2nd ed). NY: Wiley.

Wanger, M., & Schaltegger, S. (2004). The effect of corporate environment strategy choice and environmental performance on competitiveness and economic performance: An empirical study of EU manufacturing. *European Management Journal, 22*(5), 557–572.

Zhang, Z. H. (2000). *Implementation of total quality management: An empirical study of Chinese manufacturing firms*. PhD unpublished thesis. Groningen: University of Groningen.