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Universal versus contextual effects on TQM: a triangulation study using neural networks

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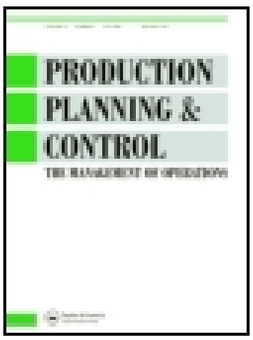

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Universal versus contextual effects on TQM: a triangulation study using neural networks

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ABSTRACT

The objective of this study is to extend previous research on total quality management (TQM)-context-performance relationships and 'fit' using multiple methods. We combine artificial neural networks (ANNs) with structural equation modelling (SEM) to analyse several hypotheses and propositions. This is the first study in this area of research that utilises ANNs and a triangulation technique in the presence of several contextual factors. The SEM analyses suggest that company size and industry type may have contingency effects on some of the TQM practices and/or TQM-performance relationships. However, the ANN models have shown that these two contingency factors do not moderate TQM outcomes, implying that all organisations can benefit from TQM regardless of size and type. As well, these models show that formal TQM implementation and/or ISO certifications do not add any predictive power to the ANN models except in one case: TQM implementation and/or ISO certification added to organisational effectiveness and customer results to predict financial and market (F&M) results. The results further indicate that even though implementing TQM alone has a bigger impact on F&M results than obtaining ISO certification alone, combining the two will have an even greater impact on these results. Joint implementation leads to greater improvements in organisational effectiveness, which, in turn, has a positive effect on customer results and consequently F&M results. This is a unique finding within the context of moderator effects on TQM-performance relationships.

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Total quality management; contextual factors; business results; artificial neural networks; structural equation modeling; survey

1. Introduction

Despite decades of industry focus on quality improvement, even reputable companies, such as Johnson & Johnson (Thomas 2013), Honda (Soble 2015), and Volkswagen (Boston 2016) continue to struggle with quality and safety problems and lose large profits as a result of recall-related costs and tarnished image. Similar problems also persist in developing countries, but total quality management (TQM) implementation in these countries still remains under-researched (Zakuan et al. 2010). As well, since quality development is at different stages in developed and developing countries, further research is needed to understand the level of TQM practices and the performance effects of these practices in developing economies (Laosirihongthong, Teh, and Adebanjo 2013). Sila and Ebrahimpour (2002, 2003) argued that information on the nature and stage of TQM implementation in some regions of the world, such as Asia, South America, Africa and the Middle East is scant. Thus, issues surrounding TQM practices and firm performance are as relevant as ever to today's businesses around the globe.

Investigating the reasons for and the implications of differences in firm productivity and performance across firms is an important topic in various fields, including production, trade, labour, industrial organisation and macroeconomics. Management capability drives organisational performance and productivity, which, in turn, contribute to economic growth and competitiveness (Agarwal et al. 2013). We focus on how this capability within the TQM context affects organisational performance in different areas. Managers are especially interested in understanding the effects of TQM implementation on their business (O'Neill, Sohal, and Teng 2016). Therefore, this study seeks to contribute to this understanding and shed light on some of the unresolved issues in the literature.

After years of empirical research in this area, there is still an ongoing debate over the universality versus the context-dependence of TQM practices and TQM-performance relationships. Findings across various studies continue to be mixed (see Table 1), where some of the studies provide support for the universality argument (e.g. Prajogo 2005; Yeung, Cheng, and Lai 2006; Sila 2007; Tawfik Mady 2009; Abusa and Gibson 2013), while other studies support context-dependence (e.g. Santos-Vijande and Álvarez-González 2007; Haar and Spell 2008; Jayaram, Ahire, and Dreyfus 2010; Zhang, Linderman, and Schroeder 2012). However, given that each study usually utilises a limited set of contextual factors at best, which often vary from study to study, it is probably incorrect to make any generalisations about the contextual nature of TQM and TQM-performance relationships based on a

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Table 1. The findings of previous studies on contextual effects.

Study	Objectives	Contingency factors	Institutional factors	Theory	Sample and methodology	Findings
Prajogo (2005)	To analyse how industry type (manufacturing vs. service firms) moderates the level of implementation of TQM practices and the effect of these practices on quality performance	Industry type***			Surveyed 194 manufacturing and service firms in Australia Used SEM and MANOVA	No significant differences were found between the two industries in terms of the applicability of most of the TQM practices and the influence of these practices on quality performance
Yeung, Cheng, and Lai (2006)	To assess the importance of company size, duration of TQM adoption, and TQM implementation as contingency factors in TQM-performance relationships	Firm size***	Duration of TQM adoption****, TQM implementation***	Institutional theory	Survey of 225 electronics manufacturing firms in Hong Kong Used multivariate general linear model	TQM is a significant predictor of performance. However, company size, duration of TQM adoption, and formal TQM implementation are not significant contingency factors
Santos-Vijande and Álvarez-González (2007)	To test the relationships among TQM implementation, innovative culture, and technical and administrative innovations		Market turbulence*		Survey of 93 manufacturing and service firms in the Asturias region of Spain Used SEM	TQM has a strong direct impact on innovativeness and administrative innovation, whereas its relationship with technical innovation is mediated by innovativeness. Market turbulence moderates these relationships
Sila (2007)	To examine the effects of contextual factors on TQM factors and TQM-performance relationships	Firm size**** and scope of operations****	TQM implementation***, ISO 9000 registration***, and country of origin****	Contingency and institutional theory	Survey of 286 US firms Used SEM	None of the five contextual factors moderated the implementation of the seven TQM factors. As well, the five contextual factors largely did not moderate the effects of TQM on four performance measures and the relationships among these measures
Haar and Spell (2008)	To assess TQM adoption rates and the effect of firm size on adoption rates	Firm size*			Survey of 228 New Zealand firms Used hierarchical regression	Level of workplace autonomy, use of performance standards, use of teams, and use of group problem solving had a positive relationship with TQM adoption. Large firms were more likely to adopt TQM than small firms
Tawfik Mady (2009)	To test the influence of industry type and firm size on the implementation level of TQM practices	Firm size** and industry type***			Survey of 105 Kuwaiti firms Used t-tests and ANOVA	Industry type had no impact on the implementation level of TQM practices, while firm size produced mixed results
Hoang, Igel, and Laosirihongthong (2010)	To analyse the relationship between TQM and organisational characteristics (size, type of industry, type of ownership, and degree of innovation)	Firm size, industry type, and degree of innovation*			Survey of 222 manufacturing and service companies in Vietnam Used SEM, MANOVA, and t-tests	Large companies implemented TQM practices more than SMEs. Manufacturing companies had higher levels of TQM implementation than service companies. A higher degree of innovation also correlated positively with TQM implementation
Jayaram, Ahire, and Dreyfus (2010)	To study the relationships among culture, quality system design, and outcomes, and the effects of contextual factors on these relationships	Firm size, TQM duration, unionisation, and industry*		Contingency theory	Survey of 395 US firms Used SEM	Firm size, TQM duration, industry type, and unionisation moderate the effects of culture and quality system design on final outcomes
Kull and Wacker (2010)	To examine the effects of various cultural dimensions in Asian countries on the relationship between quality management practices and product quality performance	Cultural dimensions: future orientation***, institutional collectivism***, humane orientation***, uncertainty avoidance*, assertiveness*, power distance***		Detert et al.'s (2000) theory	Used survey data collected by the Manufacturing Research Group, which consists of 913 samples from 15 countries and 21 industry classifications Used Hierarchical Linear Model approach	There are differences in quality management effectiveness across China, South Korea, and Taiwan. As well, some of the cultural dimensions are significantly associated with quality management effectiveness, whereas organisation size and per capita GDP are not

Zatzick, Moliterno, and Fang (2012)	To analyse how the fit between strategic orientation and TQM affects performance	Strategic orientation*		The internal fit of TQM with the strategic orientation of the firm's activity system	Used longitudinal data from 780 Canadian manufacturing firms Used Hierarchical OLS regression	TQM improves performance for cost leaders but lowers it for differentiators
Zhang, Linderman, and Schroeder (2012)	To investigate the impact of contextual factors on the relationship between quality management practices and manufacturing performance	Organisational structure*		Contingency theory	Survey of 238 manufacturing plants in three industries across eight countries Used confirmatory factor analysis, regression, and ANOVA	Organisational structure and environmental uncertainty moderate TQM's effect on manufacturing performance
Abusa and Gibson (2013)	To examine the degree to which TQM influences organisational performance in companies that are ISO 9000-certified and in those that are not		ISO 9000 certification****		Survey of 56 Libyan companies Used Pearson's correlation and regression analysis	Process management and top management commitment were found to be the most important TQM factors, among several TQM factors, in terms of their impact on operational performance (OP). There were no significant differences between ISO 9000-certified and non-ISO 9000-certified companies in terms of the effect of TQM on various OP measures, except exports growth
Singh, Dean, and Chee-Chuong (2013)	To test the Deming management method using moderating and contextual factors	Positional authority, length of tenure*		Deming management method	Used data from 367 civil servants from 5 public-sector organisations in Singapore Used SEM and MANOVA	The Deming management method is applicable to public sector organisations in Singapore. Positional authority and length of tenure of employees moderate the relationships between the constructs in the model
Wiengarten et al. (2013)	To assess the impact of innovativeness on the performance effects of TQM practices	Innovativeness*		Contingency theory	Survey of 894 companies located in Belgium, Italy, Ireland, and the UK Used SEM	Innovativeness moderates the relationship between TQM and operational performance

*Significant; **Partially significant; ***Nonsignificant; ****Largely nonsiginificant.

single study or even several studies. Furthermore, these studies have often used different models and different sets of TQM practices and performance measures. Sousa and Voss (2008) also contend that different results across studies may be partly due to different contextual and performance variables being used.

To be able to make a reliable assessment of the effects of contextual factors, similar measures must be used across different studies. Therefore, in this study, we use Sila's (2007) TQM-performance relationships model as a framework and extend it by utilising multiple contextual factors and methods. One of the important contributions of this study is our use of triangulation between different approaches to fit (in this case, interaction and system approaches), which is absent from contingency research in operations management (Sousa and Voss 2008). In fact, the use of triangulation in operations management research has been generally limited (Jack and Raturi 2006). As well, one of the methods we use, artificial neural networks (ANNs), has not been used in this area of research before.

Triangulation offers several important benefits to researchers. It increases confidence in research results and can stimulate the creation of inventive methods and new ways of capturing a problem to balance with conventional data-collection methods. Triangulation can also help detect the deviant or off-quadrant dimension of a phenomenon. Since different viewpoints may produce some elements which do not fit a theory or model, old theories can be refashioned or new theories can be developed. In addition, multiple methods may yield divergent results, enhancing our understanding of the research problem. The use of multiple methods can help synthesise or integrate theories, as well as serve as the critical test, by virtue of its comprehensiveness, for competing theories (Jick 1979). Choi, Cheng, and Zhao (2016) also argue that triangulation increases the scientific merit of operations management research, since it enables researchers to validate the findings and conclusions, thus reducing the risk of making biased conclusions.

2. Theoretical framework

2.1. Study model

The TQM-performance relationships model (Figure 1) developed by Sila (2007) is proposed for the current study. Table 2 summarises the hypotheses and propositions developed in this section.

The quality management literature emphasises the importance of internal customers in addition to external customers, simply because satisfied internal customers will work harder to satisfy the requirements of external customers. Therefore, human resource management (HRM) practices should be effectively integrated with TQM to meet the needs of internal customers (Youssef, Youssef, and Ahmed 2014). TQM requires that a company develop an organisational culture that values open communication, high performance and an engaged workforce. A company can engage its workers by providing them with workplace safety, security and support; offering development and advancement opportunities; giving appropriate workload and compensation; encouraging open communication and teamwork; empowering them; and so on (NIST 2015). As a result, TQM can help improve employee satisfaction and loyalty (Karia and Asaari 2006; Chang, Chiu, and Chen 2010), employee performance (Sadikoglu and Zehir 2010), employee involvement (Karia and Asaari 2006; Tang, Chen, and Wu 2010), organisational learning (Lee et al. 2012) and quality of work life (Ooi et al. 2013). Thus:

TQM has a direct, positive effect on human resource results.

High levels of workforce engagement can also significantly improve other areas of organisational performance (NIST 2015). For example, employee satisfaction and loyalty can lead to increased customer satisfaction and loyalty (Yee, Yeung, and Cheng 2008, 2010; Jung and Yoon 2013), which may subsequently improve financial and market (F&M) results (Yee, Yeung, and Cheng 2008, 2010; Chi and Gursoy 2009). These relationships have also been established by previous empirical studies using the service–profit chain framework. This conceptual framework links employee satisfaction and loyalty, customer satisfaction and loyalty, and financial performance (Loveman 1998). A meta-analysis conducted by Hogreve et al. (forthcoming) found that all the links proposed in the service–profit chain are statistically significant and substantial.

The relationship between employee satisfaction and customer satisfaction is also implicit in the Deming management method. Customer satisfaction is viewed as a natural outcome of the employees' ability to achieve pride of workmanship. Within the context of Deming's 14-point quality management philosophy, pride of quality of work depends on meeting customers' changing

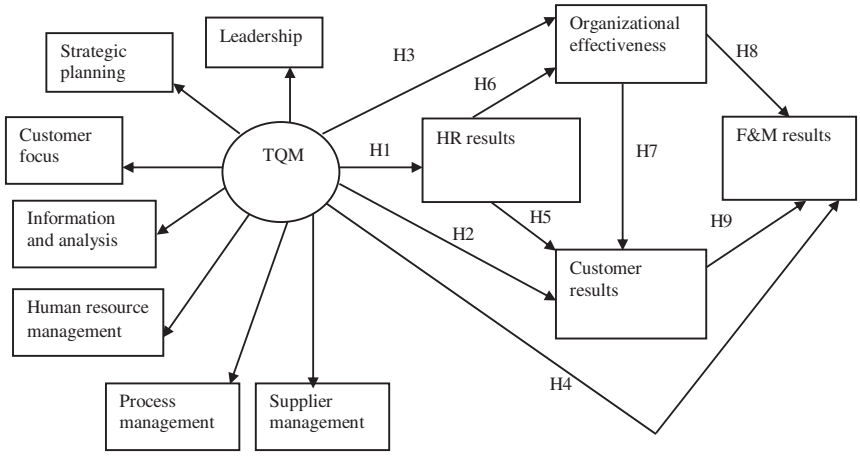

Figure 1. A model of the relationships among TQM and key organisational performance measures.

Table 2. A summary of the model hypotheses and contextual propositions.

Hypotheses	Explanation
H1	TQM has a direct, positive effect on HR results
H2	TQM has a direct, positive effect on customer results
H3	TQM has a direct, positive effect on organisational effectiveness
H4	TQM has a direct, positive effect on F&M results
H5	HR results have a direct, positive effect on customer results
H6	HR results have a direct, positive effect on organisational effectiveness
H7	Organisational effectiveness has a direct, positive effect on customer results
H8	Organisational effectiveness has a direct, positive effect on F&M results
H9	Customer results have a direct, positive effect on F&M results
Institutional propositions	
TQM implementation	
Proposition 1.	TQM practices are different across TQM companies and non-TQM companies
Proposition 2.	The structural model relationships are different across TQM and non-TQM companies
ISO certification	
Proposition 3.	TQM practices are different across ISO-certified and non-ISO-certified companies
Proposition 4.	The structural model relationships are different across ISO-certified and non-ISO-certified companies
TQM implementation and ISO certification	
Proposition 5.	TQM practices are different across both ISO and TQM, only ISO or TQM, and neither ISO nor TQM companies
Proposition 6.	The structural model relationships are different across both ISO and TQM, only ISO or TQM, and neither ISO nor TQM companies
Contingency propositions	
Company size	
Proposition 7.	The fit of some of the TQM practices is similar, whereas the fit of some practices differs across small, medium and large companies
Proposition 8.	Some of the the structural model relationships are similar, while others differ across small, medium and large companies
Industry type	
Proposition 9.	The fit of some of the TQM practices is similar, whereas the fit of some practices differs across manufacturing and service companies
Proposition 10.	The structural model relationships are similar across across manufacturing and service companies

requirements, furnishing them with pertinent information about products or services and predicting customer usage (Anderson et al. 1995). This relationship has been found to be significant by some of the previous empirical studies (e.g. Anderson et al. 1995; Rungtusanatham et al. 2005) using the Deming management method as a framework. Gounaris and Boukis (2013) find that employee job satisfaction not only affects customer satisfaction but customers' perception of quality as well. It also leads to the development of high relational switching costs. This discussion leads us to the following two hypotheses from Table 2:

Human resource results have a direct, positive effect on customer results.

Customer results have a direct, positive effect on F&M results.

Job satisfaction can improve firm performance if it increases employee work effort and reduces unnecessary on-the-job activities (Böckerman and Ilmakunnas 2010). In fact, Böckerman and Ilmakunnas (2010) find that a one standard deviation improvement in establishment job satisfaction would improve productivity (one of the organisational effectiveness measures in our study) by 6.6%. Brown and Lam's (2008) finding indicates that job satisfaction leads to improved service quality – another measure of organisational effectiveness – which, in turn, helps increase customer satisfaction.

Figure 1 shows that both customer results and organisational effectiveness are proposed to mediate the relationship between HR results and F&M results. The HR results-organisational effectiveness-F&M results link can also be seen in Kacmar et al.'s (2006) proposed employee turnover-efficiency-profit model. The model was tested using a sample of restaurants and the results showed that efficiency, measured as customer wait time, mediated the relationships of both management and crew turnover to both sales and profit. A more recent work by Prakash et al. (2017) has also explored the organisational effectiveness-performance relationship. By analysing the home-based brassware units in India, the authors found evidence for the argument that quality leads to productivity, which, in turn, results in improved business performance (a composite of financial and non-financial measures). Therefore, we posit:

Human resource results have a direct, positive effect on organisational effectiveness.

Organisational effectiveness has a direct, positive effect on F&M results.

Organisational effectiveness measures such as product or service quality can also directly influence customer results. For example, high service quality is likely to lead to customer satisfaction, brand loyalty and long-term relationships with customers (Hussain, Al Nasser, and Hussain 2015). In addition to offering high quality, companies can also produce customer value by lowering their costs and increasing cycle time (Atkins et al. 2002). Thus:

Organisational effectiveness has a direct, positive effect on customer results.

Consistent with the literature, we also propose that TQM is directly related to customer results. According to Deming (1982), customer satisfaction is the most important goal of implementing TQM. TQM requires that organisations develop processes that 'capture stated, unstated, and anticipated customer requirements, expectations, and desires' (NIST 2015). Various methods, such as surveys, focus groups and social media, must be used to collect and integrate customer-related data. Clearly, the goal is to determine customer satisfaction and dissatisfaction. The root causes of dissatisfaction should be identified and resolved to avoid future dissatisfaction (NIST 2015).

Previous empirical studies reported a positive relationship between TQM and customer satisfaction (e.g. Mehra and Ranganathan 2008; Sit et al. 2009; Ooi et al. 2011). Other empirical studies (e.g. Agus and Abdullah 2000; Sila 2007) also found that customer satisfaction played a mediating role in the link between TQM and financial performance, which is captured by our theoretical model. Therefore:

TQM has a direct, positive effect on customer results.

According to Deming (1986), quality improvement reduces waste and cost and improves financial performance. By engaging in sole sourcing, companies can also minimise total costs as a result of reduced variability in suppliers' products, improve product quality, and minimise costs of delay and rework (Deming 1986). Firms focusing on total quality are also expected to attain high levels of productivity and competitiveness (Pinho 2008).

However, previous findings on TQM's direct effect on financial performance are mixed, in that some studies reported significant effects (e.g. Hendricks and Singhal 1997; Handfield, Ghosh, and Fawcett 1998; Tanninen, Puumalainen, and Sandström 2010), while others did not (e.g. Sila 2007; Kober, Subraamanniam, and Watson 2012). This is likely due to the presence of intermediate factors affecting this relationship (which we also test in this study) or the time lag needed to realise the positive effects of TQM implementation on financial outcomes (Calvo-Mora et al. 2014). Hence, we posit:

TQM has a direct, positive effect on organisational effectiveness.

TQM has a direct, positive effect on F&M results.

2.2. TQM-context-performance relationships and fit

Sila (2007) used institutional and contingency theory as a framework to formulate institutional and contingency propositions. In addition to the factors in the original study, we use industry type as an additional contingency factor and the presence or absence of both formal TQM implementation and ISO certification in a company as additional institutional factors.

2.2.1. Institutional propositions

2.2.1.1. Formal TQM implementation and ISO certification. The traditional perspective is that formal TQM implementation and ISO certification will lead to higher levels of TQM practices and performance, since firms that systematically implement TQM allocate more resources and effort for these activities (Sila 2007). However, the findings of previous empirical studies on this hypothesis are mixed. For example, Sila (2007) reported no differences between TQM and non-TQM companies and between ISO and non-ISO companies. On the other hand, Punnakitikashem et al. (2010) found a higher level of implementation of TQM practices at TQM companies than non-TQM companies.

Another related issue is whether firms should either implement TQM or obtain ISO certification, or whether they should pursue both to realise the best outcomes. Researchers are divided over this issue as well. Some (e.g. Gotzamani and Tsiotras 2001; Magd and Curry 2003) argue that ISO 9001 certification should precede TQM implementation, since TQM and ISO 9001 have common practices (though TQM is more comprehensive) and obtaining ISO 9001 certification first lays the groundwork for future TQM implementation. Using this strategy, Prabhu et al. (2000) suggest, firms will have higher levels of performance. Similarly, Sun (2000) asserts that jointly implementing TQM and ISO 9001 certification in an integrated fashion increases the effectiveness of the quality system.

However, Martínez-Lorente and Martínez-Costa (2004) contended that ISO 9001 principles contradict with the TQM philosophy and that companies applying both systems would reap fewer benefits than if they implemented only one of these systems. In addition, the authors found a positive relationship between TQM and operational results, but not between ISO 9001 and operational results. Terziovski, Samson, and Dow's (1997) results corroborate this finding and suggest that, on average, ISO 9001 certification has little or no explanatory power of organisational performance. As a result, Martínez-Lorente and Martínez-Costa (2004) recommended that firms should rather implement TQM and pursue ISO 9001 certification only when forced to do so by customers. In this study, we aim to shed light on these inconsistent findings by testing propositions 1–6 listed in Table 2.

2.2.2. Contingency propositions

2.2.2.1. Company size. The TQM principles first originated in large companies and the subsequent literature mostly focused on the implementation of TQM in these companies (Ghobadian and Gallear 1997). Some authors (e.g. McAdam and McKeown 1999) argued that TQM implementation favoured smaller companies due to their flatter management structures and higher flexibility, while others suggested that the more formalised and specialised (e.g. Germain and Spears 1999) and abundant resources (e.g. Ghobadian and Gallear 1997; van der Wiele and Brown 1998) of large companies facilitated TQM implementation. Sun and Cheng (2002) distinguished between small and medium-sized companies (SMCs) and large companies in terms of their motivation to implement TQM. They argued that large companies undertake TQM initiatives to survive and reduce costs, whereas SMCs are mainly driven by their goal to meet customer requirements. As a result, large companies focus on the hard elements of TQM, such as training, feedback and supplier management, while SMCs emphasise the soft elements, such as leadership and employee involvement (Sun and Cheng 2002).

However, previous studies examining the effects of firm size on TQM practices and TQM-performance relationships reported mixed findings. Powell's (1995) findings showed that large firms were more likely to adopt TQM than small firms, but the negative correlation between size and TQM performance suggested that size may hinder the successful implementation of TQM. On the other hand, while Sila (2007) found no significant overall effects of firm size, Jayaram, Ahire, and Dreyfus's (2010) findings indicated that firm size was a significant moderator. In the Jayaram, Ahire, and Dreyfus (2010) study, some of the TQM-performance relationships were stronger for large firms, whereas the others were stronger for small size firms. This, the authors claimed, indicated the presence of instances where the nimbleness of small firms gave them an advantage, and other instances where the scale advantages enjoyed by large firms favored them. Given some of these previous arguments and findings about the effects of size, we postulate propositions 7 and 8 shown in Table 2.

2.2.2.2. Industry type. As is the case with many of the contextual factors, the reported effects of industry type on TQM by previous studies have been mixed. Some of these studies compared the implementation of TQM across manufacturing and service sectors. Prajogo's (2005) motivation to compare the two sectors arose from the fact that the TQM principles originated in the manufacturing sector and that they could be less applicable to services. However, the author found no significant differences between the two sectors in terms of the

applicability of most of the TQM practices and the effects of these practices on quality performance. This finding, the author argued, provided support for the robustness of TQM principles.

Powell (1995) posited that manufacturing firms that implemented TQM would outperform their service counterparts for the same reasons put forth by Prajogo (2005), but his findings were a little different from those of Prajogo (2005). Manufacturing firms were more satisfied with their TQM programs, because they utilised some of the hard TQM practices (closeness to suppliers, zero defects mentality, process improvement and measurement) more successfully (Powell 1995). Some of the previous literature (e.g. Beaumont, Sohal, and Terziovski 1997; Terziovski, Samson, and Dow 1997; Woon 2000) are also consistent with Powell's (1995) finding that hard TQM practices are implemented at a higher level in manufacturing companies. However, further testing by Powell (1995) indicated that manufacturers did not outperform service firms, since they could not surpass service firms in the implementation of practices that have important performance effects: namely, the intangible areas, including open organisation, employee empowerment and executive commitment (Powell 1995).

Although Hoang, Igel, and Laosirihongthong (2010) used TQM practices that were somewhat similar to those used by Prajogo (2005) and Powell (1995), only one of the hard TQM practices, information and analysis, and customer focus were implemented at a higher level in manufacturing companies. The other practices tested displayed no differences across the two sectors. However, the overall effect of industry type on TQM practices was significant.

Clegg, Gholami, and Omurgonulsen (2013) also found that TQM practices were widely implemented in both manufacturing and service sectors, but these practices were statistically more significant in the manufacturing sector. Manufacturers were focused on TQM's 'quality, profitability, and improvement' related practices to improve operations performance. They also used improvement initiatives to enhance secondary organisational performance (which corresponds to F&M results in our study). On the contrary, the service sector emphasised TQM practices pertaining to 'people, products and services' and used operational improvements as a means to achieve positive secondary organisational performance.

Overall, the literature suggests that there are both similarities and differences in the implementation of TQM practices across manufucturing and service companies. Based on Prajogo (2005) and Powell's (1995) findings, however, we expect no differences in the performance outcomes of manufacturing and service companies. Therefore, we posit propositions 9 and 10 listed in Table 2.

Among the three forms of fit (selection, interaction and system approach) put forth by Drazin and van de Ven (1985) for contingency research, we focus on the interaction and system approaches. Sousa and Voss (2008) also discuss these forms of fit from an operations management perspective. The selection approach examines the relationships between a single contextual factor and a single response variable, whereas the interaction approach looks at how a single contextual factor and a single response variable interact to affect performance. On the other hand, the system approach involves an analysis of the effects of multiple contextual factors and response variables on performance simultaneously (Drazin and van de Ven 1985). In this study, the structural equation modelling (SEM) models look at the interaction fit between the model variables – the model variables being the 7 TQM practices measuring the TQM construct, the TQM construct and several performance measures – and a single contextual factor at a time. On the other hand, the ANN models can measure both the interactive and the system fit. The use of both the interaction and the system approaches is scant in operations management contingency research (Sousa and Voss 2008).

In addition, Montagno, Sexton, and Smith (2002), whose findings suggest that ANNs can identify combinations that result in better approximations of performance, as compared to standard statistical techniques, argue that ANNs should be considered as an appropriate tool for performance improvement strategy selection. The interaction approach is useful in identifying the most important context-practice relationships. If fit is identified only among certain pairs of context-practice relationships, this would suggest that these relationships are more important determinants of performance and that scarce resources should be allocated to such relationships. The system approach is more useful in helping us to understand organisational design by analysing context-practice-performance relationships holistically (Drazin and van de Ven 1985).

2.3. Artificial neural networks

ANNs have long been used to solve a number of difficult problems in business, engineering, medicine and other fields (e.g. Montague and Morris 1994; Smith and Gupta 2000; Detienne, Detienne, and Joshi 2003; Liao and Wen 2007). ANNs are ideal for complex business problems, in that they are noise resistant (once trained), nonlinear and non-parametric classifiers that utilise machine learning techniques to optimise model output (Walczak and Cerpa 1999). The ANNs discussed in this article utilise the supervised learning backpropagation learning method. Backpropagation trained ANNs have been proven to be able to accurately approximate solutions surfaces of arbitrary complexity (Hornik, Stinchcombe, and White 1989). ANNs are composed of layers of processing elements, as shown in Figure 2. The first layer or input layer is equivalent to the independent variables in any statistical model and the final or output layer is the dependent variable. One or more hidden layers exist between the input and output layers, where relationships between the independent and dependent variables are learned. The optimal number of hidden layers depends on the degree of nonlinearity involved in the solution surface (Walczak and Cerpa 1999). Each processing element is connected to the processing elements in the subsequent layers, where each connection has a weight variable.

Learning occurs in supervised learning ANNs by passing back the average difference for each epoch of training between the ANNs output layer values and the correct values supplied with the training sample. This value is used to adjust the weights on the interlayer connections, strengthening or weakening weights on the connections to move the output values closer to the true values, similar in some aspects to gradient descent algorithms, but with decreasing randomisations to prevent becoming trapped in a local minima. Training is terminated once the ANN reaches a predefined cut-off value, typically 0.05 root mean square error (RMSE) or when the RMSE does not decrease after a prespecified number of training epochs.

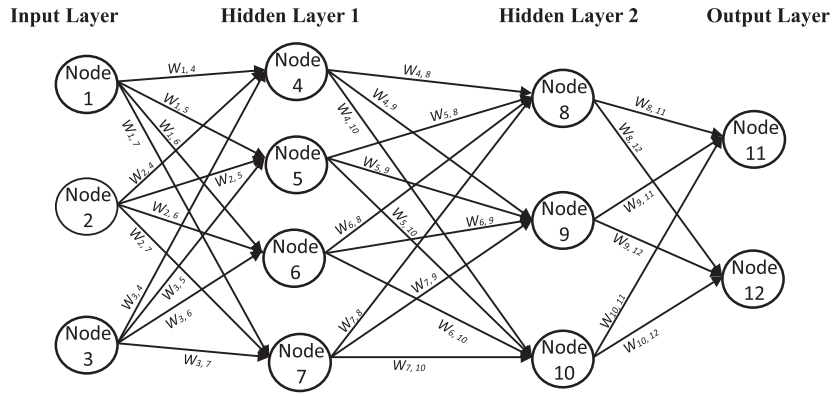

Figure 2. Sample ANN architecture.

2.4. ANNs and TQM

The modeling power of ANNs has largely not been used to model TQM outcomes. ANNs have been used to model various aspects of operations management: quality in technical education (Mahapatra and Khan 2007), water quality management (Zaheer and Bai 2003), workflow and manufacturing management (Jeyapaul, Shahabudeen, and Krishnaiah 2005; Cheng and Ma 2008), statistical process control in multivariate manufacturing processes (Yu and Xi 2009), sales channel selection (Chong et al. 2013) and the effects of adopting an interorganisational system standard (Chan and Chong 2012).

The use of an ANN to provide output data which is then further interpreted by a constructed mathematical heuristic algorithm is known as (non-concurrent) methodological triangulation as formalised by Walczak (2012). Methodological triangulation using ANNs has been previously used in other business-related research. Chan and Chong (2012) use an SEM and ANN combined approach to classify the determinants of standards adoption by organisation. Chong (2013) uses a combined SEM and ANN to identify prerequisites for adopting a mobile e-commerce strategy. Wong et al. (2011) use the PC algorithm in place of SEM to better identify dependent and independent constraints for an ANN model to optimise supply chains. The authors use an SEM approach to perform component analysis, and the results from SEM are then used in an ANN to predict the adoption of an interorganisational system standard. However, methodological triangulation using ANNs is still missing from TQM-performance relationships research.

3. Methodology

3.1. Measurement instrument

As mentioned above, we used a modified version of Sila's (2007) instrument to avoid some of the problems associated with using different measures across different studies and to be able to perform comparable analyses. We translated the instrument to Turkish and asked several business academicians who were fluent in both English and Turkish to review the translations and assess the readability of the instrument. After making the required changes, we also received feedback on the instrument from several companies' managers and made further changes to refine it. As a result, the final instrument consisted of 50 items measuring the 7 TQM factors and 19 items measuring the four performance variables. We used a 1–5 Likert scale to measure the TQM factors (1 = strongly disagree and 5 = strongly agree) and the four performance measures (1 = extremely low and 5 = extremely high). For each performance measure, we asked the respondents to rate the level of their site's performance during the past 3 years compared to major industry competitors.

3.2. Sample

Since one of our objectives was to compare manufacturing and service companies in Turkey, we randomly selected 1000 manufacturing and 1000 service companies from the list of members of Istanbul Chamber of Commerce. We administered an online survey to these companies in late 2012. Of the 169 returned, 13 were outliers and were therefore deleted. As a result, 156 usable responses remained. The number of responses from the two sectors was roughly equal, with 80 manufacturing and 76 service companies that represented the various industries of the national business sector, allowing us to make comparisons between the two sectors. Non-response bias was assessed by conducting t-tests on early and late respondents' mean responses to 10 randomly selected questions (Armstrong and Overton 1977), which indicated that there were no significant differences between the two groups. The two groups were also similar in terms of sales and number of employees in support of the conclusion that there was no non-response bias in the data.

3.3. Scale reliability and validity

A confirmatory factor analysis (CFA) for each model variable was carried out to test whether each item loaded significantly on its assigned construct. Table 3 shows that all the factor loadings are significant. Other tests, including unidimensionality, reliability, convergent validity, discriminant validity and criterion-related validity were also conducted. The unidimensionality of the variables was assessed using the CFA results. Since there was slight multivariate non-normality in the data, we used the Satorra-Bentler (S-B) scaled chi-square (χ^2) and the robust comparative fit index (CFI) values. We assessed model fit for all CFA and SEM models in this study using a CFI cutoff value of 0.90 together with a standardised root mean square residual (SRMR) value of less than 0.10 (Kline 2005). As indicated in Table 3, the CFI values

Table 3. CFA results for model variables.

Model constructs and their indicators	S-Bχ^2	df	S-Bχ^2/df	*p*-Value	Robust CFI	SRMR	Factor loading*	Cronbach's alpha
TQM	39.3152	14	2.81	0.00033	0.970	0.029		0.940
Leadership							0.795	0.845
Strategic planning							0.910	0.916
Customer focus							0.756	0.816
Information and analysis							0.904	0.880
Human resource management							0.886	0.917
Process management							0.879	0.898
Supplier management							0.769	0.886
Human resource results	5.2536	2	2.63	0.07231	0.98	0.033		0.790
Employee turnover							0.656	
Employee absenteeism							0.695	
Number of employee suggestions							0.741	
Employee job performance							0.700	
Customer results	2.2030	2	1.10	0.33237	1	0.022		0.820
Customer retention							0.817	
Reliability and timely delivery of products/services							0.819	
Personalised service							0.625	
Value for the money spent							0.667	
Organisational effectiveness	24.0269	9	2.67	0.00426	0.96	0.046		0.862
Cost							0.611	
Product/service quality							0.768	
Productivity							0.846	
Cycle times							0.802	
Number of errors or defects							0.624	
Supplier performance							0.620	
Financial and market results	33.1153	5	6.62	0.00000	0.91	0.072		0.848
Market share							0.686	
Profit							0.797	
Return on total assets							0.851	
Overall competitive position							0.726	
Number of successful new product/service introductions							0.563	

*$p < 0.01$.

ranged from 0.91 to 1.00, and the SRMR values ranged from 0.022 to 0.072, providing support for the unidimensionality of all the constructs.

We analysed the reliability of the constructs with Cronbach's alpha (Cronbach 1951). All the alpha values were greater than 0.70 (Table 3), suggesting high construct reliability (O'Leary-Kelly and Vokurka 1998). All of the items loaded significantly on their assigned constructs with factor loadings ranging from 0.563 to 0.910, thus providing evidence for convergent validity (Bagozzi, Yi, and Phillips 1991).

Discriminant validity tests involved a series of χ^2 difference tests between nested CFA models for all pairs of constructs. Table 4 shows that all of the difference tests are significant and therefore we can argue for strong disciminant validity (Bagozzi, Yi, and Phillips 1991). In addition, the correlations between the TQM construct and each of the four performance mesasures were 0.596, 0.478, 0.515 and 0.594, respectively ($p < 0.001$), which suggested that there was strong criterion-related validity.

3.4. ANN model development

Identification of non-correlated yet meaningful independent variables is critical to the success of ANN models (Smith 1993; Walczak and Cerpa 1999). Therefore, methodological triangulation is used to determine meaningful relationships between the independent and dependent variables (Walczak 2012) using an SEM model (Figure 1) to identify relationships, which are then

Table 4. Discriminant validity analysis.

Construct scale pairs	Unconstrained		Constrained		
	χ^2	df	χ^2	df	$\Delta\chi^2$
TQM					
Human resource results	109.32	43	206.38	44	97.06*
Customer results	92.60	43	181.62	44	89.02*
Organisational effectiveness	144.66	64	250.55	65	105.89*
Financial and market results	145.39	53	236.18	54	90.79*
Human resource results					
Customer results	58.27	19	80.10	20	21.83*
Organisational effectiveness	94.92	34	125.83	35	30.91*
Financial and market results	115.88	26	150.08	27	34.20*
Customer results					
Organisational effectiveness	62.62	34	132.12	35	69.50*
Financial and market results	119	26	143.42	27	24.42*
Organisational effectiveness					
Financial and market results	165.50	43	204.37	44	38.87*

*$p < 0.001$.

used to design the ANN model. The variables for the ANN models are derived from the survey instrument described previously. Independent variables are constructed as the average of individual responses for each of the seven TQM practices: leadership, strategic planning, customer focus, information and analysis, HRM, process management and supplier management. These seven variables are always used collectively and are referred to as the TQM7 variables and are only used as independent (input) variables to the ANN models. The average values for all survey instrument questions for each of the four TQM outcomes is used to create the four variables: HR results, organisational effectiveness, customer results, and F&M results. The first three of the results variables are utilised both as dependent (output) variables and also as independent variables in some of the ANN models. The F&M result variable is only used as a dependent variable.

The ANNs developed for our research utilise the backpropagation supervised learning algorithm, with a hyperbolic tangent transfer function and a learning epoch size of 16 samples. The backpropagation learning method is selected due to the perceived data quality with low to moderate noise (Walczak and Cerpa 1999). Multiple architectures, including both single and two hidden layer architectures with varying quantities of processing nodes in each of the hidden layers, are evaluated for each ANN model. Training continued for a minimum of 50,000 iterations and ended when the RMSE of the ANN's output stabilised for 500 iterations. Once training was completed, the validation set was run through the ANN a single time.

Two experiments are conducted. The first experiment evaluates the efficacy of using ANNs to predict TQM outcomes, utilising the TQM model above to define the independent and dependent variable sets. For this first experiment, the two hidden layer architectures uniformly outperformed the single hidden layer architectures. This indicates a convoluted nonlinear solution surface and may help explain why previous research using more traditional parametric and linear methods has led to inconclusive results. The best performing ANN architecture for each outcome prediction model in the first experiment tended to have N nodes in the first hidden layer (N = the number of input variables) and the second hidden layer was close to $N/2$. An ANN architecture for experiment 1 is shown in Figure 3(a) with connections not shown for clarity.

The second experiment evaluates the effect of contextual factors on TQM outcomes. Only the best performing ANN model for each TQM outcome is used in experiment 2 to provide a basis for comparing performance effects. Therefore, only two hidden layer ANN architectures are attempted for experiment 2. The independent contextual factors for experiment 2 represent the size of the company (small, medium or large), the type of business (service or manufacturing) and whether or not the organisation had formally implemented TQM or was ISO registered. Each of these three variable sets is treated as a categorical variable for

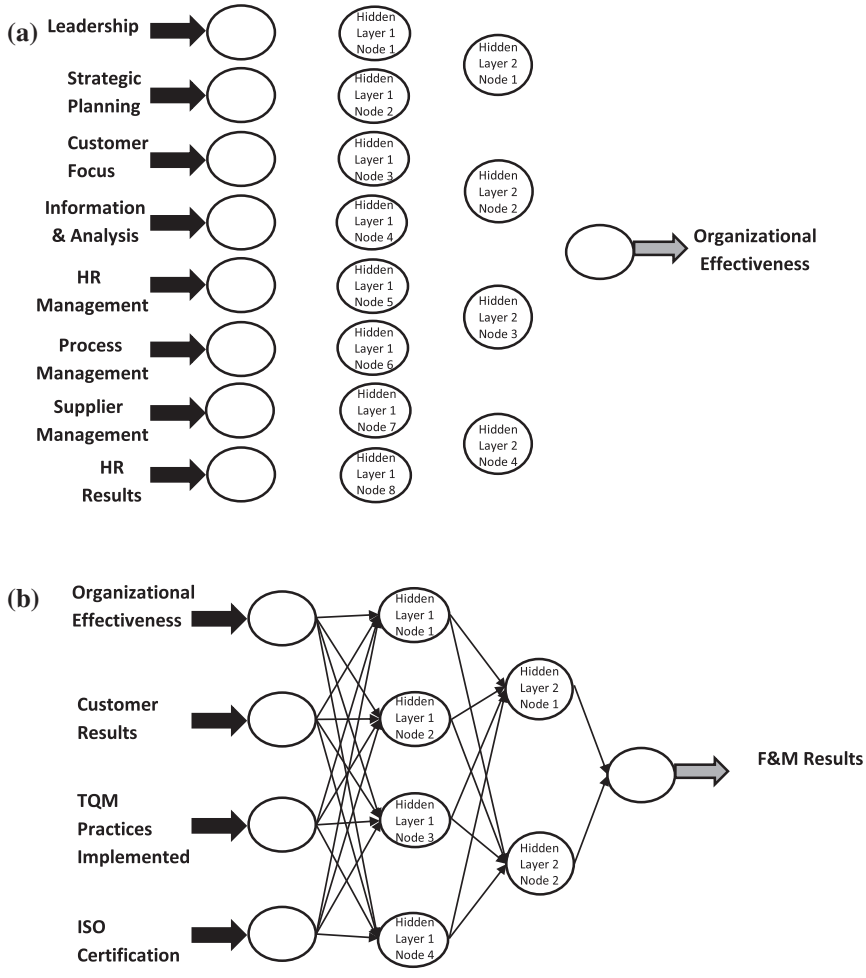

Figure 3. Sample architectures of ANNs to predict TQM outcomes. (a) Research experiment 1 ANN to predict organisational effectiveness. (b) Research experiment 2 ANN to predict F&M outcomes.

the ANN implementations. The three sets of categorical variables are added in a full factorial design to the best performing ANNs from the first experiment, so that each combination of possible contextual factors is evaluated, yielding seven new models per dependent variable. A sample ANN architecture for experiment 2 is shown in Figure 3(b).

The impact of contextual factors may be evaluated by examining how these new input variables affect the prediction performance of ANN models that predict TQM outcomes. If the context variables are universally applicable, then the performance of all ANNs that have this universal contextual variable added should improve over their results from the first experiment. If the context variables are applicable, but in a contingency way, then some, but not all of the ANNs with this new variable added should improve. A result of no performance improvement in any of the ANN models for a specific contextual variable implies that the corresponding variables do not impact the TQM outcomes.

4. Results

4.1. Structural path model results

Using EQS 6.2 for Windows, we ran the proposed model for the full sample and the subgroup samples (Table 5). The CFI values ranged from 0.92 to 1.00, and the SRMR values ranged from 0.039 to 0.087, signaling adequate model fits for all of the subgroup samples. The parameter estimates for the full sample are shown in Figure 4, which suggests that all of the hypotheses except H4 and H5 are supported. The 7 factors loaded significantly on the TQM construct across all samples. Consistent with the full sample, we found H4 and H5 to be non-significant across all the subgroup samples. In fact, the results of the 9 hypotheses were mostly consistent across all samples. These results also agree with Sila's (2007) research findings. We also conducted multiple group analysis (MGA) to test the invariance of the model relationships across subgroups within each institutional and contingency factor as discussed below.

4.2. MGA results

Since our propositions focused on the equality of TQM factors and model relationships across subgroup samples of each contextual factor, we imposed equality constraints on factor loadings and structural paths using the methods described by Byrne (2006). Table 6 lists the overall model fit indices before and after constraints are released using the Lagrange Multiplier (LM) test to identify where non-invariance lies in the model (see Table 7). Three of the contextual factors (TQM implementation, ISO certification, industry type) had adequate model fits after the initial model run (i.e. CFI was above 0.90 and SRMR was less than 0.10). The 'ISO and TQM' factor had an adequate model fit only after one non-significant constraint was released. Company size

Table 5. Structural path model analyses.

Contextual factor	Subgroup	*N*	S-Bχ^2	df	S-Bχ^2/df	*p*-Value	Robust CFI	SRMR
All data		156	79.46	39	2.04	0.00014	0.96	0.041
TQM implementation	TQM	69	44.45	39	1.14	0.25296	0.99	0.040
	Non-TQM	87	80.75	39	2.07	0.00010	0.93	0.059
ISO certification	ISO	82	50.89	39	1.30	0.09625	0.98	0.045
	Non-ISO	74	68.73	39	1.76	0.00230	0.94	0.056
ISO and TQM	Both ISO and TQM	57	42.82	39	1.10	0.31052	0.99	0.042
	Only ISO or TQM	38	60.64	39	1.55	0.01477	0.92	0.087
	Neither ISO nor TQM	61	69.29	39	1.78	0.00200	0.93	0.056
Company size	Small (0–20 employees)	79	40.18	39	1.03	0.41781	1.00	0.045
	Medium (20–100 employees)	41	57.07	39	1.46	0.03086	0.95	0.071
	Large (>100 employees)	35	48.33	39	1.24	0.14528	0.97	0.056
Industry type	Manufacturing	80	72.49	39	1.86	0.00089	0.94	0.060
	Service	76	63.71	39	1.63	0.00750	0.95	0.039

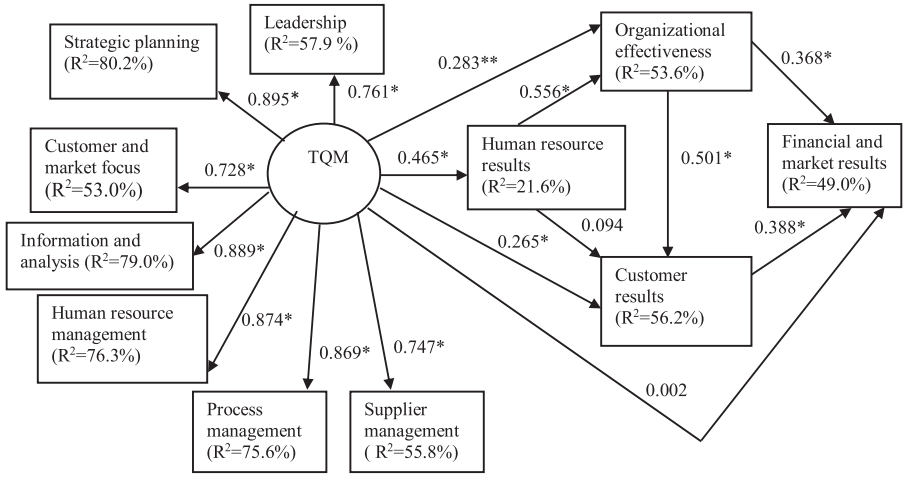

Figure 4. Empirical results for the full sample. Fit indices: S-Bχ^2 = 79.46; df = 39; S-Bχ^2/df = 2.04; *p*-Value = 0.00014; Robust CFI = 0.96; SRMR = 0.041. $^{*}p < 0.001$; $^{**}p < 0.01$.

had a good fit only after several constraints were released and was the only factor with a large number of non-invariant model relationships (11 of the 16 factor loadings/structural paths were non-invariant) across its subgroups.

Thus, in terms of overall model fit, TQM implementation, ISO certification, ISO and TQM, and industry type had no contextual effects, whereas company size did. However, in terms of individual model relationships, each contextual factor had 1–11 non-invariant factor loading(s) or structural path(s) (see Table 7), with industry type and company size having a relatively larger number of such noninvariances. Thus, there are only some contextual effects on some of the TQM practices and structural model relationships. As shown in Table 7, propositions 1, 3 and 5 are not supported, while there are very little support for propositions 2, 4 and 6. However, propositions 7, 8, 9 and 10 are supported. Interestingly, H9 (the effect of customer results on F&M results) was consistently non-invariant across all model runs, except the one for industry type.

A more detailed analysis of the results summarised in Table 7 and comparisons with the results of previous studies suggest the following regarding the effects of contextual factors:

4.2.1. The effects of formal TQM implementation and ISO 9000 certification

Consistent with Sila's (2007) findings, these two institutional factors had no significant effects based on the overall model fit. However, in terms of the individual model relationships, an interesting pattern emerged with regards to hypothesis 9: contrary to Sila's (2007) finding with US firms, the effect size of the relationship between customer results and F&M results was significantly larger in TQM than non-TQM companies and in ISO-certified than non-certified companies. In addition, the effect size of this relationship was significantly larger in companies that implemened both TQM and ISO and in those companies that implemented either TQM or ISO, as compared to companies that implemented neither. We elaborate further on this result in section 4.3.2. with more detailed information obtained from the ANN results.

4.2.2. The effects of company size

The MGA results suggest that company size affects both the overall model fit and many of the individual model relationships. Leadership, customer focus, and information and analysis are implemented similarly in small, medium, and large companies. On the other hand, process management and supplier management are implemented at a higher level in large companies. This is consistent with Sun and Cheng's (2002) argument that large companies focus on the so-called hard elements of TQM. However, this argument did not hold for information and analysis, another hard TQM element.

The results show that strategic planning is also implemented at a higher level in large companies than in SMCs. This agrees with the previous literature, which finds that strategic management techniques are applied extensively in large companies (Kraus 2007). On the other hand, the scarcity of resources and the lack of sufficient business-related knowledge on the part of top managers prevent SMCs from implementing formal strategic planning successfully (Karagozoglu and Lindell 1998; Kraus, Reiche, and Reschke 2007). As a result, planning in SMCs tend to be 'rather

Table 6. Multiple group analyses results.

	Before constraints are released						After constraints are released						
Contextual factor	S-Bχ^2	df	S-Bχ^2/df	*p*-Value	Robust CFI	SRMR	S-Bχ^2	df	S-Bχ^2/df	*p*-Value	Robust CFI	SRMR	Model fits?
TQM implementation (TQM and non-TQM)	144.8067	93	1.56	0.00047	0.95	0.086	140.0286	92*	1.52	0.00093	0.95	0.080	Yes, both before and after 1 constraint is released
ISO certification (ISO and non-ISO)	133.6767	93	1.44	0.00367	0.96	0.087	128.713	92**	1.40	0.00694	0.96	0.077	Yes, both before and after 1 constraint is released
ISO and TQM (both ISO and TQM, only ISO or TQM, neither ISO nor TQM)	197.2058	147	1.34	0.00361	0.95	0.109	191.2143	146**	1.31	0.00711	0.96	0.098	Yes, but only after 1 constraint is released
Company size (small, medium, and large)	195.8665	147	1.33	0.00437	0.96	0.129	162.0295	136***	1.19	0.06334	0.98	0.086	Only after several constraints are released
Industry type (service and manufacturing)	162.2191	93	1.74	0.00001	0.93	0.091	151.7711	90****	1.69	0.00005	0.94	0.076	Yes, both before and after constraints are released

*1 non-significant constraint was released. Constraints have been released only if fit is significantly improved; **1 non-significant constraint was released; ***11 non-significant constraints were released; ****3 non-significant constraints were released.

Table 7. Invariance analysis of TQM practices and structural model relationships across subgroups of each contextual factor.

TQM factor/Hypothesis	Effect of	Effect on	TQM implementation (TQM and non-TQM)	ISO registration (ISO and non-ISO)	ISO and TQM [both ISO and TQM (1), neither ISO nor TQM (2), only ISO or TQM (3)]	Company size [small (1), medium (2), and large (3)]	Company type (service and manufacturing)
Leadership			Invariant	Invariant	Invariant	Invariant	Invariant
Strategic planning			Invariant	Invariant	Invariant	All 3 groups noninvariant	Invariant
Customer focus			Invariant	Invariant	Invariant	Invariant	Invariant
Information and analysis			Invariant	Invariant	Invariant	Invariant	Noninvariant
HRM			Invariant	Invariant	Invariant	(1) and (3) invariant (2) noninvariant with (1) and (3)	Noninvariant
Process management			Invariant	Invariant	Invariant	All 3 groups noninvariant	Noninvariant
Supplier management			Invariant	Invariant	Invariant	(1) and (2) invariant. (3) noninvariant with (1) and (2)	Invariant
H1	TQM	Human results	Invariant	Invariant	Invariant	(1) and (3) invariant. (2) noninvariant with (1) and (3)	Invariant
H2	TQM	Customer results	Invariant	Invariant	Invariant	Invariant	Invariant
H3	TQM	Organisational effectiveness	Invariant	Invariant	Invariant	Invariant	Invariant
H4	TQM	Financial and market results	Invariant*	Invariant*	Invariant*	Invariant*	Invariant*
H5	HR results	Customer results	Invariant*	Invariant*	Invariant*	(1) and (2) invariant. (3) noninvariant with (1) and (2)*	Invariant*
H6	HR results	Organisational effectiveness	Invariant	Invariant	Invariant	invariant	Invariant
H7	Organisational effectiveness	Customer results	Invariant	Invariant	Invariant	(1) and (2) invariant. (3) noninvariant with (1) and (2)	Invariant
H8	Organisational effectiveness	Financial and market results	Invariant	Invariant	Invariant	(1) and (2) invariant. (3) noninvariant with (1) and (2)	Invariant
H9	Customer results	Financial and market results	Noninvariant	Noninvariant	(1) and (3) invariant. (2) noninvariant with (1) and (3)	All 3 groups noninvariant	Invariant
Contingency/institutional effects based on overall model fit?			No	No	No	Yes	No
Contingency/institutional effects based on individual model relationships?			Yes, but only 1 out of the 16 factors/relationships exhibits differences	Yes, but only 1 out of the 16 factors/relationships exhibits differences	Yes, but only 1 out of the 16 factors/relationships exhibits differences	Yes, 11 out of the 16 factors/relationships exhibit differences	Yes, 3 out of the 16 factors/relationships exhibit differences
Propositions regarding the factors			P1 not supported Very little support for P2	P3 not supported Very little support for P4	P5 not supported Very little support for P6	P7 supported P8 supported	P9 supported P10 supported

*The hypothesis is non-significant for all subgroups.

unstructured, sporadic, incremental, and often informal' (Kraus 2007).

As shown in Table 7, the effects of company size on structural model relationships are mixed. The relationship between HR results and customer results are significant and negative for large firms, whereas it is positive for SMCs. In addition, the relationship between organisational effectiveness and F&M results is non-significant for large firms, while it is positive and significant for SMCs. However, two of the other bivariate relationships – organisational effectiveness-customer results and customer results-F&M results – have significantly larger effect sizes for large firms compared to SMCs. These findings agree with those of Jayaram, Ahire, and Dreyfus (2010), who also report some stronger TQM-performance relationships for large firms and other relationships that are stronger for smaller firms.

4.2.3. The effects of industry type

Our findings on industry type's effect on TQM practices are in line with those of Powell (1995), since two of the hard TQM practices, including information and analysis and process management, are implemented at a higher level in manufacturing companies. Prajogo (2005) reported a higher level of implementation of information and analysis in manufacturing firms as well. Our results show that HRM is also applied more rigorously in manufacturing companies. This may seem in conflict with Powell's (1995) study, where the author finds manufacturing firms' implementation of soft practices, such as open organisation, employee empowerment and executive commitment, to be similar to those of service firms. However, our findings may not be directly comparable to his, since we used a more comprehensive HRM construct that integrated various HRM elements, whereas he used different elements of HRM as separate measures (e.g. employee empowerment, training).

In terms of structural model relationships, our study indicates no differences in TQM outcomes between the two sectors. This is consistent with some of the previous studies, including Powell (1995) and Hoang, Igel, and Laosirihongthong (2010), where Powell (1995) also reports no differences and Hoang, Igel, and Laosirihongthong (2010) find only one such difference. However, unlike Hoang, Igel, and Laosirihongthong (2010), we find that the overall effect of industry type on the proposed model relationships is not significant. Only three of the TQM practices are impacted by this contigency factor.

4.3. Artificial neural network results

4.3.1. Experiment 1: efficacy of predicting TQM outcomes with an ANN model

The ANN models require a baseline for comparison of their results. A simple comparison, though unrealistic, would be to use a random value approach for the baseline, which would produce random prediction results that were on average 20% correct. A more accurate approach would be to incorporate the maturity of the Turkish markets for service and manufacturing organisations. This is done by finding the most frequently occuring value amongst all the responses for each TQM outcome with the results: HR Results (30.77%), organisational effectiveness (38.46%), customer results (38.46%) and F&M results (44.87%).

The ANN output on the validation set for each model is considered correct if it is within 0.5 of the actual value. This approach avoids the problem of deciding if rounding, minimising or maximising the output value is the most appropriate and instead uses a nearness criterion for determining the correctness of the output values. The ANN results are listed in Table 8 (best performance in bold), which shows the input vector variables along with the corresponding prediction values for appropriate TQM outcome variables. If a connection does not exist in the SEM model between variables and outcomes, then no results are possible and may be seen in Table 8 as N/A values. No single value input vectors are evaluated in this research. When compared to the most frequently occurring values, all of the ANN models' prediction results are significantly better ($p < 0.01$). Only the F&M prediction models which were not ranked as the best performing lacked statistical significance. Thus, each of the ANN models is significantly better at predicting individual company TQM-oriented results than using average sample results to indicate individual corporate performance capabilities. The machine learning capabilities for ANNs and the resultant nonlinear models utilise and are able to identify significant factors for individual organisations rather than simply using averages of the industry composite as would occur in using a regression-based model.

The ANN models confirm several claims from the SEM model shown in Figure 4, which is used to generate the independent variable sets. The improvement in the prediction accuracies of the ANN models predicting organisational effectiveness indicates that HR results definitely contribute to the predictability of the organisational effectiveness outcome variable, when combined with the seven TQM practices. Additionally, the poor results for the ANN models predicting the F&M results when the TQM7 variables are used as independent variables strongly indicates that the TQM7 variables are definitely not significant for estimating this TQM outcome variable. However, the ANN models imply that the TQM7 variables also have no effect on the customer results

Table 8. ANN outcome prediction results.

Independent variables	HR results	Organisational effectiveness	Customer results	F&M results
TQM7	53.85%	48.72%	52.56%	35.90%
TQM7, HR results	N/A	57.69%	53.85%	N/A
TQM7, Organisational effectiveness	N/A	N/A	65.38%	46.15%
TQM7, HR results, Organisational effectiveness	N/A	N/A	55.13%	N/A
TQM7, Customer results	N/A	N/A	N/A	41.03%
TQM7, Organisational effectiveness, Customer results	N/A	N/A	N/A	41.03%
HR results, Organisational effectiveness	N/A	N/A	69.23%	N/A
Organisational effectiveness, Customer results	N/A	N/A	N/A	51.28%

outcome variable, in contradiction to the SEM findings above. This may be caused by a side effect of using an ANN model. Recall that input variable selection is critically important (Walczak and Cerpa 1999) and furthermore non-correlated variables are required as input variables (Smith 1993). Since the ANN models have shown that the TQM7 variables can accurately predict HR results outcomes for individual organisations over 53% of the time, it may be that the effect of the TQM7 variables is already captured in these two outcome variables, which produce the best performance for predicting customer results outcomes and thus including them again introduces a correlation conflict in the ANN model. While this is only preliminary evidence, it indicates that further research is required to evaluate the need for using these TQM practices when predicting either customer results or F&M results.

The values shown in Table 8 strongly support H1 and H3 and contradict H2 and H4. The ANN models also provide strong support for hypotheses H5 through H9, as each of the antecedent variables is used in the ANN model, producing the best TQM outcome prediction performance and provides statistically significant differentiation from the sample mode.

4.3.2. Experiment 2: using ANNs to evaluate the effect of contextual factors

The best performing ANNs for each outcome variable in experiment 1 is expanded by adding in categorical contextual factors. The results for these 28 new ANN models are shown in Table 9. As shown in Table 9, the three contextual variables do not add any predictive power to the ANN models except in one case: both TQM implementation and ISO certification added to organisational effectiveness and customer results to predict F&M results. As discussed earlier, the MGA findings also found non-invariant effects for the relationship between customer results and F&M results and that this relationship was stronger when companies implemented either TQM or ISO or both than when they implemented neither. However, this finding was limited only to the relationship between customer results and F&M results. ANNs have complemented this finding by showing further that the TQM-organisational effectiveness-customer results-F&M results path in our theoretical model is strengthened with the implementation of both TQM and ISO. This finding is unique in the literature. Overall, this supports Prabhu et al. (2000) and Sun's (2000) argument that the joint implementation of TQM and ISO will result in superior firm performance. However, it contradicts with that of Terziovski, Samson, and Dow (1997) and Martínez-Lorente and Martínez-Costa (2004), who predict no and fewer performance improvements with joint implementation, respectively.

The evidence indicates that using any combination of company size, industry type, and TQM/ISO does not impact the predictability of HR results, organisational effectiveness, or customer results. The lower results for these three prediction variables indicate that although the ANN modeling paradigm is trying to incorporate this additional information, the new information is in fact only noise that detracts from each model's performance (Zhang 2007).

The two TQM/ISO categorical variables used as a group may indicate that neither TQM implementation nor ISO certification has been attempted, or both have, or just one of these. Two additional ANN models are developed to determine whether implementing TQM practices or obtaining ISO certification causes this effect singularly. These two new ANNs are identical to the original F&M results prediction ANN, but using only the TQM practice implementation categorical variable or the ISO certification categorical variable. The results from this experiment indicate that using both TQM and ISO variables results in 51.95% prediction accuracy, while using just TQM yields 49.35% and just ISO yields 39.74% prediction accuracy.

The results from the second experiment provide evidence for the even-numbered propositions on structural model relationships (the ANN models did not test the odd-numbered propositions). Minor support, particularly with respect to F&M results, is gained for Propositions 2, 4 and 6. Since Proposition 10 indicates that industry type should not affect the TQM outcomes, this proposition is supported by the results. However, the ANN models indicated that company size did not have any effect on TQM outcome result predictability and therefore Proposition 8 is only partially supported by ANN results.

5. Discussion and study implications

The ANN results shown above confirm the general TQM model proposed, with the exception that TQM affects customer results not directly but, instead, through the mediating effects of HR results. HR results and organisational effectiveness may be seen as internal results (i.e. close to the core operation of the organisation) and are thus directly affected by internal organisational practices, while customer results and F&M results may be seen as more external results or products of the organisation and are therefore only indirectly affected by TQM practices through other internal and external results. This classification of TQM outcomes into internal and external results is a recommendation of the research.

Although various architectures were used for the ANN modeling, only the best performing ANN models are reported and not

Table 9. ANN prediction results using contextual factors.

Context variable(s) added	HR results prediction (%)	Organisational effectiveness prediction (%)	Customer results prediction (%)	F&M results prediction (%)
None	53.85	57.69	69.23	51.28
Company size (Size)	38.96	54.55	63.64	40.26
Size, TQM implementation and/or ISO certification (TQM/ISO)	32.47	46.75	63.64	37.66
Size, Industry type	42.86	46.75	68.83	50.65
Size, TQM/ISO, Industry type	35.06	50.65	64.94	42.86
TQM/ISO	45.45	51.95	62.34	51.95
TQM/ISO, Industry type	36.36	44.16	36.36	47.44
Industry type	50.00	51.28	64.10	37.18

every possible architecture was developed. Therefore, the ANN results reported should be taken as the minimum possible.

5.1. Managerial implications

Most of the previous empirical studies in this area focused on the analysis of companies in developed countries. This study's findings suggest that the implementation of TQM practices can significantly improve firm performance as it relates to employees, customers, organisational effectivess and F&M success in a developing country context. We recommend that managers of companies of different sizes implement these practices to improve their companies' performance in different areas. We find that large companies, possibly due to the scale and complexity they have to deal with, emphasize some of the hard elements of TQM, such as process management and supplier management, more than SMCs. This is understandably so and may not require any special action on the part of SMCs' managers to improve these practices, but strategic planning is one area where SMCs need to improve their formal planning capabilities. This will result in further improvements in company performance. Even though some of the characteristics of SMCs (e.g. flatter management structures and higher flexibility) will favor SMCs in improving performance in some areas, the characteristics of large firms (e.g. ample resources, being more formalised and specialised) will help them become more successful in other performance areas when implementing TQM practices. However, given these trade-offs, the overall performance outcomes may not necessarily favor firms of a certain size over others. In fact, the ANN results show that companies of different sizes can achieve similar overall performance outcomes as a result of their TQM practices.

This study also suggests that both manufacturing and service companies can implement similar TQM practices and reap similar performance benefits. Manufacturing companies implement some of the hard TQM elements, including process management and information and analysis, at a higher level than service companies. The fact that they still achieve similar performance results in all areas imply that this is more likey related to differences in sectoral characteristics than a lack of knowledge or emphasis on the service sector's part on the importance of these practices.

Given limited organisational resources, managers are often confronted with the question of whether they should only seek ISO 9001 certification or implement TQM or do both. However, there are conflicting recommendations in the literature on this issue. Based on our findings, we recommend that managers do both, since performance gains as a result of joint implementation will be greater. We also determined the mechanism through which these gains will be realised: joint implementation will lead to greater improvements in organisational effectiveness, which will then result in improvements in customer results and consequently F&M results.

The ANN models developed for this research indicate that we can predict outcomes for individual organisations significantly better than we can for a group of organisations. Utilising similar tools, organisational leadership can predict the likely outcome of changing any of the seven TQM practices and obtain a measure of how successful their organisation is at realising the tauted outcome benefits of TQM based on the specific context they operate in.

5.2. Research implications

Previous empirical studies in this area have mainly utilised single methods to analyse TQM-performance relationships. However, our research combines two strong methods – SEM and ANN – to test these relationships, while accounting for the effects of various contextual factors. Sousa and Voss (2008) found that there are only a few studies that used both the interaction approach and the system approach in operations management contingency research.

The research reported in this article has indicated that TQM outcomes should be divided into internal outcomes and external outcomes. These internal and external outcomes require different levels of information (such as external outcomes only being affected indirectly by internal business practices) in order to accurately model the respective outcomes and this should be incorporated into future TQM research models.

The ANN models also show that the contextual factors of company size and type of business do not facilitate any type of distinction in outcome differences between organisations. Both the ANN and SEM models agree that there are no institutional (except TQM implementation and/or ISO certification added to organisational effectiveness and customer results to predict F&M results) or contingency effects (except company size, which was found to have significant contingency effects by SEM) based on overall fit. However, there were conflicting findings between the two methods concerning the contextuality of some of the individual model relationships. That is, mutiple group analysis findings reported in Table 7 suggested the existence of a few TQM practices and structural model relationships that were contextual. This was especially the case for company size, with 11 of the 16 factors or relationships in the model having differences across companies with different sizes. However, the ANN models found the contextual factors to be noise variables because these models were able to produce better prediction performance when the contextual factors were not present. The ANN analyses conducted in this study suggest a convoluted nonlinear solution surface, whereas SEM, which was utilised by most previous research as well, uses more traditional parametric and linear methods.

Another explanation for such conflicting findings could be that the SEM analyses produced only interaction results and that the ANN analyses yielded interaction as well as system results. According to Drazin and van de Ven (1985), since the interaction approach analyses the interactive effects of a single contextual factor and a single response variable on performance, it cannot identify the effects of fit that exist at a holistic level. Therefore, interaction results should be compared with system results. Non-significant interaction results but significant system results would indicate that fit occurs not at the level of any individual variable alone but at a holistic level (Drazin and van de Ven 1985), which may result because more complete information is available to the system level model. Thus, it could be argued that even if company size was significant at the individual level (based on SEM results), it was not significant at a holistic level (based on ANN results). In addition, the fact that the sample sizes for the subgroups of company size were small may also be part of the reason behind these inconsistencies. Therefore, larger subgroup sample sizes must be used in future research. Although SEM requires large sample sizes, ANNs can produce accurate results with relatively small sample

sizes. In addition, different company size classifications are being used in different parts of the world, which may result in conflicting findings across different studies.

Future research may still continue to examine the variables used in this research, but this should be done with the inclusion of additional contextual variables such as country-level and cultural factors or expanding the existing ones to include a finer distinction between business types (i.e. different industries). The contextual variables of ISO certification and TQM implementation efforts have been shown to affect F&M results and thus bears further examination. The body of knowledge gained from the SEM and ANN findings indicates that while some of the model relationships exhibit context-dependence, others do not. Therefore, it is best not to make generalisations about the effects of contextual factors but rather narrow down the analysis to these factors' effects on specific TQM practices and TQM-performance relationships, while distinguishing between different forms of fit. The systems approach includes the equifinality argument, which suggests that fit between the set of practices and organisational context can be achieved in numerous, equally effective ways (Drazin and van de Ven 1985; Sousa and Voss 2008). Therefore, it is important that additional contextual factors that organisations face be integrated into the ANN models to analyse how different configurations of TQM practices and contextual factors affect TQM outcomes.

This study also has implications for institutional theory. Some of the previous studies have suggested that institutional factors, called non-efficiency factors, forced manufacturing companies to adopt TQM practices due to coercive (e.g. customer pressure for ISO 9000 certification or TQM implementation), mimetic (e.g. imitation of Japanese manufacturing practices) and normative (e.g. regulatory pressure to obtain ISO 9000 certification) pressures. Thus, companies may be more concerned about gaining legitimacy than improving their performance, which resulted in their implementation of certain practices that were not effective in their context (Sousa and Voss 2008). However, there is also empirical evidence in the literature, showing that the relationship between TQM implementation (e.g. Powell 1995) or ISO certification (e.g. Lee and Palmer 1999) and business performance are positive. It could be argued that these inconsistent findings may be in part due to the differences in the degree of institutional pressures faced by companies sampled in different studies. The findings of the current study also partially agree with the non-efficiency argument, since TQM implementation and/or ISO certification did not significantly moderate most of the model relationships. However, the ANN findings indicated that formal TQM implementation and/or ISO certification did significantly moderate the effect of TQM on F&M results through organisational effectiveness and customer results. This implies that the moderating effects of institutional factors may be more complex than previously thought.

5.3. Research limitations

Potential bias may have been introduced into the data by the fact that we relied on the respondents' perceptions about their organisation's TQM practices and performance measures. In addition, the ANN approach used in this research primarily utilises the backpropagation learning methodology. Some radial basis function (RBF) learning method ANNs were also developed in the early stages of the research, but the backpropagation trained ANNs consistently outperformed these RBF trained ANNs. Other training methods exist and future research may examine if another learning methodology, such as bayesian trained ANNs or unsupervised learning methods may outperform the current backpropagation ANNs. Although multiple ANN architectures were examined, not every possible architecture was evaluated and future research may be able to determine the optimal architecture.

The population size for the SEM and subsequent ANN models is 156 organisations. All ANNs used n-fold cross validation, in which the sample is divided into randomly selected binary groups: one for training and one for validation, until each member of the population is used at least one time in a validation set, thus allowing the validation set size to be equal to the population size of 156. Only one result for each of the 156 member population is used and that was for the first time that subject organisation appeared in a validation set. The ANN results reported in Table 8 had ANNs with connections ranging from 10 to 81. The smallest ANN reported in Table 9 had 31 connections and the largest ANN had 222. Since the training data represented only 100 samples (where each sample is a unique member of the study population), a question may arise if this was sufficient to keep the larger ANN models from simply memorising the data. The learning capability of ANNs enables them to overcome small training populations. In fact, prior research has reported on successful ANN model development for an ANN architecture with 26 connections that was trained using only 4 data samples (Walczak and Krause 1995). Additionally, recall that the results reported are for the out-of-sample validation results and thus even if any memorisation were occuring, it would most likely not be applicable to these previously unseen data samples.

6. Conclusions

This is the first study in TQM-context-performance relationships and fit research that utilises ANNs and a triangulation technique in the presence of several contextual factors. In this study, we used ANNs as both a learning and non-parametric methodology to model TQM results. We developed supervised learning using backpropagation learning ANN models by utilising methodological triangulation (Walczak 2012). An SEM model provided confirmation of independent variables and dependent variables, as well as potential relationships between these variables. ANN models that were developed to predict the four TQM outcome results for individual businesses were able to outperform the sample norms (taken as the mode value for all businesses in the sample) in predicting the TQM outcome measures for HR results, organisational effectiveness, customer results and F&M results.

The ANN results showed that contextual factors of company size and type of business were irrelevant to predicting TQM outcomes for individual businesses, whereas the interaction results obtained from SEM analyses pointed toward some contextual effects. Based on the ANN results, we can also conclude that the contextual factors for obtaining ISO certification and implementing TQM have a positive effect on F&M results. Such potential gains in F&M performance should motivate the upper management to be even more committed to the implementation of these quality systems.

Disclosure statement

No potential conflict of interest was reported by the authors.

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