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The Relationships between the Pillars of TPM and TQM and Manufacturing Performance Using Structural Equation Modeling

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Abstract: This paper examines the direct and indirect relationships between the pillars of total quality management (TQM) and total productive maintenance (TPM) and investigates their effects on manufacturing performance (MPR) using structural equation modeling. Three structural models were developed with their corresponding hypotheses. Data were then collected from thirty industrial firms in Jordan. A descriptive statistical analysis was followed by an analysis of variance (ANOVA). The structural models were analyzed to draw conclusions about the model hypotheses and identify the most influential TPM and TQM pillars on MPR. Significant variations were noticed among firms in the implementation levels of the TPM, TQM, and MPR pillars. Further, it was found that TPM directly and indirectly influences MPR. Furthermore, TPM pillars have a larger impact on MPR than TQM. Research hypotheses are suggested to be tested individually on small-, middle-, and large-sized firms. This research provides valuable information on top management in the industrial sector, on the significant relationships between the pillars of TPM, TQM, and MPR and supports them in identifying important TQM/TPM pillars which they should focus on in order to enhance MPR.

Keywords: total productive maintenance; total quality management; MPR; structural equation modeling

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1. Introduction

Intense global competition and ever-changing customer demands have forced many firms to continually improve their performance through effective management programs, such as total quality management (TQM) and total productive maintenance (TPM) [1–12]. Ineffective maintenance practices made most manufacturing processes operate at a low productivity level and with high manufacturing costs. To mitigate or eliminate such negative outcomes, TPM was developed, which is a proactive and cost-effective program for equipment maintenance that aims to maximize the overall equipment effectiveness throughout the equipment lifetime and strives to maintain optimal equipment conditions to prevent unexpected breakdowns, speed losses, and quality defects arising from process activities [13,14]. It is divided into three important concepts: (i) total, which implies the involvement of all personnel/employees of the company, (ii) productive, which means that TPM activities/activities is executed as much as possible and does not interfere with the productivity of the company, and (iii) maintenance, which requires the selection of the most appropriate/effective method of maintenance [14–16]. Recently, several studies have focused on TPM implementation and examined its effects on business performance. For example, Bamber et al. [17] studied the factors affecting the successful implementation of TPM in UK manufacturing. McKone et al. [18] examined the impact of TPM practices on manufacturing performance. Mehta et al. [19] carried out TPM implementation in a machine shop. Eti et al. [20] implemented TPM in Nigerian manufacturing industries. Brah and Chong [21] examined the relationship between TPM and performance. Thun [22] analyzed the dynamic implications of TPM. Wang [23] evaluated the efficiency of implementing TPM. Alsyouf [3] investigated the role of maintenance in improving company productivity and profitability. Lazim et al. [24] examined the relationship between TPM and performance in Malaysian industries. Ahuja and Khamba [25] presented a literature review and directions related to TPM. Kocher et al. [26] presented an approach for TPM and factors affecting its implementation in a manufacturing environment. Wickramasinghe and Perera [27] stated that the adoption of TPM enhances business performance. Rathi et al. [28] identified the total productive maintenance barriers in Indian manufacturing industries.

On the other hand, TQM practices seek to continually enhance and sustain the quality of products and related processes by the reduction of the variation from a production process or service-delivery system, thereby increasing its efficiency, reliability, and quality [29–31]. A high level of organizational performance is often gained through teamwork, customer-driven quality, and improvements in inputs and processes [31–33]. The implementation of TQM practices and the examination of their effects on performance have gained considerable research attention. For example, Zhang et al. [34] measured the effects of TQM in Chinese industries. Brah et al. [35] examined the influences of TQM practices on the services sector's performance in Singapore. Brah et al. [36] investigated the relationship between TQM practices and the performance of Singapore companies. Kaynak [37] related TQM practices and examined their effects on business performance. Feng et al. [38] identified the impact of TQM practices on performance through a comparative study between Australian and Singaporean organizations. Demirbag et al. [39] examined the relationship between TQM practices and the performance of Turkish Small and medium-sized enterprises (SMEs). Pandi et al. [29] studied integrated TQM practices in technical institutions from the students' perspectives. Salaheldin [40] identified the key factors for a successful adoption of TQM practices and studied their impact on SMEs performance. Miyagawa and Yoshida [41] explored the relationship between TQM practices and the performance of Japanese-owned manufacturers. Phan et al. [42] conducted an empirical study to determine the influence of TQM on the performance of Japanese manufacturing firms. Awino et al. [43] examined the effects of TQM practices on the performance of horticultural firms in Kenya. Bajaria [44] identified critical issues for an effective TQM Implementation. Islam and Haque [45] conducted an empirical study about TQM implementation in a manufacturing organization. Nawelwa et al. [46] analyzed TQM practices in Zambian secondary schools and then identified key elements of TQM. Niu and Fan [47] performed a thorough examination of TQM practices in China, which revealed that implementing TQM in any firm could be influenced by internal and external factors, along with the characteristics of the enterprise.

Performance measuring plays a critical role in a firm's continual improvement and is a key step when deciding the direction of its strategic activities. There are several criteria for measuring manufacturing performance (MPR), involving cost, quality, profitability, and employee morale. Typically, TPM and TQM value continual improvement, employee empowerment, process focus, and top management commitment. TQM explicitly emphasizes customer focus, whereas TPM implicitly considers customer dimension through waste reduction, productivity improvement, and improvising quality. Cua et al. [48] examined the relationship between the implementation of TQM, Just-in-Time (JIT), and TPM and the manufacturing performance, while Seth and Tripathi [49] tested the relationship between TQM and TPM implementation factors and the business performance of a manufacturing industry in the Indian context. Seth and Tripathi [50] conducted a critical study of TQM and TPM approaches and tested their effects on the performance of the Indian manufacturing industry. Ahuja and Khamba [25] reported that the adoption of TPM practices significantly improves the behavior in manufacturing enterprises. Teeravaraprug et al. [51] constructed a relationship model to study the supporting activities of JIT, TQM, and TPM. Konecny and Thun [52] performed an empirical analysis of a conjoint implementation of TQM and TPM on plant performance. Al-Refaie and Hanayneh [53] developed a structural model to examine the relationships between TPM, TQM, and Six Sigma practices and examined their effects on the performance of firms in Jordan.

Structural equation modeling (SEM) is a multivariate statistical analysis tool that can be employed to analyze structural relationships between the measured variables and latent constructs using both factor analysis and multiple regression analysis. SEM has been widely used to investigate relationships between improvement programs and firm performance in a wide range of business applications [54,55].

TQM is correlated to TPM. Both concepts indicate a similarity in quality, time, and cost flexibility to improve firm performance. Hence, the transfusion of TQM and TPM can enhance the quality, equipment, reliability, and productivity. Still, the inter-relationships between TQM and TPM practices with their effects on the pillars of business performance improvement must be evaluated. In some of the Jordanian industrial firms, TPM and TQM pillars have been adopted and adapted for enhancing the performance and the competition of firms. For the purpose of assessing the effectiveness of the implementation of the TPM and TQM pillars, examining the relationships between them, and studying their impacts on performance, this research develops three structural models (Model I to III); Model I examines the relationships between eight TPM pillars and seven pillars of MPR, Model II investigates the relationships between eight TPM pillars and eight TQM pillars, and Model III studies the relationships between eight TQM pillars and seven MPR pillars. The results provide a thorough understanding of the relationships between the TQM and TPM pillars, identify the most (and least) influential pillars on TQM and business performance, and guide decision makers to appropriate actions to improve the performance of the manufacturing sector in Jordan. This research is structured as follows. Section 2 develops the conceptual framework and model hypotheses. Section 3 conducts a data collection and analysis. Section 4 discusses the research results and provides the main conclusions and recommendations.

2. Conceptual Framework

In this research, eight pillars of TPM, eight pillars of TQM, and seven pillars of manufacturing performance will be considered as presented in the following subsections.

2.1. Pillars of TPM

Based on previous studies in the literature [21,23,25,27,48], eight pillars of TPM are identified, including 5S, autonomous maintenance (AM), Kaizen (KA), planned maintenance (PM), quality maintenance (QM), education and training (ET), health and safety (HS), and focused improvement (FI). The item measures of the TPM pillars are displayed in Table 1.

Table 1. The item measures of the TPM pillars.

Practice	Item Measure
5S	- Only essential items and equipment are maintained. - The plant is kept clean and neat all the time. - Emphasizes putting all tools and fixtures in their place. - Work practices are consistent and standardized. - Work standards are reviewed regularly and maintained by employees.
AM	- Assisting machine operators to make their own preventive maintenance. - Operators clean and take care of their machines regularly. - Operators maintain the operating conditions of their machines. - Operators can discover deterioration and signs of abnormalities on their machines. - A high percentage of maintenance tasks is performed by the operators

Table 1. *Cont.*

Practice	Item Measure
KA	- Employees' suggestions are encouraged and regularly evaluated and implemented. - Employees' participation in making improvements. - Waste reduction through continuous improvement.
PM	- Well-trained and highly qualified maintenance team. - Inspection schedule for all planned maintenance. - Regular maintenance meetings. - Regular preventive maintenance. - Software analysis of maintainability, reliability, and overall equipment efficiency. - Operators submit regular reports on machines' conditions and breakdowns. - Operators record the periods and frequency of machines' failures and stoppages.
QM	- Maintenance representatives in quality meetings. - Cross-functional teams are specialized in both maintenance and quality. - Cross-functional teams regularly evaluate machines 'performance.
ET	- Operators training on maintenance principles. - Operators training on equipment operation and maintenance. - Raising awareness of leadership, teamwork, and quality. - Operators can take care of simple maintenance tasks.
HS	- Safety precautions exist to ensure employees' safety. - All employees are obliged to wear protective gear and clothing. - A clinic is available to look after the health and safety of the employees. - Existence of safety signs, safety manuals, and emergency exists. - Hired safety engineers. - Availability of health insurance for all employees.
FI	- Management commitment to maintenance improvement. - Data analysis for reduction of maintenance costs and equipment losses. - Maintenance benchmarking is performed regularly. - Adoption of leading-edge technology in maintenance and reliability.

2.2. Pillars of TQM

Previous studies revealed eight TQM pillars [34,37,47,50], which are strategic planning (SP), committed leadership (CL), customer involvement (CI), employee involvement (EI), cross-functional training (CF), quality management (QG), and process management (PS). Table 2 defines the item measures of the TQM pillars.

Table 2. Item measures of the TQM pillars.

Pillar	Item Measure
SP	- A written mission, long-range goals, and strategies for implementation. - Routine review and update of the long-range strategic plan. - Vision focuses on quality improvement. - Mission statement is effectively communicated throughout the firm.
CL	- Top management commitment to improving quality. - Top management involvement in quality improvement projects. - Top management encourages employees' leadership to achieve quality improvements. - Customers' requirements are regularly surveyed.
CI	- High responsiveness to customers' needs. - Customers are asked to send their feedback on quality and delivery performance - Teams are formed to solve quality problems. - Many quality problems were solved through small group sessions

Table 2. *Cont.*

Pillar	Item Measure
EI	- Improving manufacturing processes through problem-solving teams. - Employees' recognition and award for achieving high-quality products. - Employee satisfaction is regularly measured. - Employees receive training to perform multiple tasks.
CF	- Cross-training of employees. - Employees on job learning. - Employees learn how to do only one job/task.
IF	- Performance information is available to employees. - Information showing defect rates and schedule compliance are posted for the employees. - Visual information plotting the frequency of machine breakdowns is posted on the shop floor. - Control charts are adopted in quality control. - Operators regularly record the production rate and defect rate of their equipment.
QG	- A formal well-defined quality policy, vision, and mission. - Suppliers' selection based on quality criterion. - Regular assessment of products and working environment. - Production of high-quality products. - Using statistical quality control.
PS	- Statistical techniques to evaluate process conditions. - Use of statistical process techniques to reduce process variations. - Continuous process improvement to reduce the defect rate. - Proper selection of material, equipment, and tools to produce high-quality products.

2.3. Pillars of Manufacturing Performance

Seven pillars of manufacturing performance (MPR) are considered [51,53], including cost (CT), quality (QY), delivery (DY), profitability (PF), productivity (PD), safety and hygiene (SH), and employee morale (EM). Table 3 displays the item measures of the pillars of manufacturing performance.

Table 3. Item measures of the MPR pillars.

Pillar	Item Measure
CT	- Unit cost is used in costing products. - Use of activity-based costing to gain higher productivity and reduce cost.
QY	- Quality means conformance to specifications. - Internal scrap and rework percentages are monitored. - Defect rate is monitored regularly. - Quality products are those meeting customers' needs and expectations. - Customers evaluate products' quality on a regular basis.
DY	- Average lead-time is monitored. - Percentage of on-time deliveries. - Delivery of the right items and the right quantities.
PF	- Profitability is the main performance measure. - Market Share is monitored. - Use of the latest technology. - Focus on profitable products.
PD	- Flexibility to changeable demand volume. - Continual improvements in machine productivity. - Continual improvements in labor productivity.
SH	- Safety and health of employees is a main top management concern.
EM	- Seeking high overall employee satisfaction. - High team spirit.

2.4. Hypotheses Development

Based on previous studies and the views of industrial experts, the hypothesized relationships between the TPM, MPR, and TQM pillars are developed as shown in Table 4. Then, the corresponding structural models I and II that depict these proposed hypotheses are depicted in Figures 1 and 2, respectively. Similarly, the proposed hypotheses in Model III that relate the pillars of TQM and MPR are displayed in Table 5 and Figure 3.

Table 4. Hypotheses relating the TPM pillars to the MPR and TQM pillars.

Model I: TPM and MPR		Model II: TPM and TQM	
H1a	5S is positively and directly related to SH.		
H1b H1c	AM is positively and directly related to PD. AM is positively and directly related to CT	H2a H2b	AM is positively and directly related to EI. AM is positively and directly related to SF.
H1d H1e	KA is positively and directly related to QY. Kaizen is positively and directly related to PF.	H2c H2d H2e H2f H2g	KA is positively and directly related to EI. KA is positively and directly related to SP. KA is positively and directly related to QG. KA is positively and directly related to PS. KA is positively and directly related to CL.
H1f H1g H1h H1i	PM is positively and directly related to DY. PM is positively and directly related to CT. PM is positively and directly related to PF. PM is positively and directly related to PD.	H2h H2i H2j	PM is positively and directly related to IF. PM is positively and directly related to QG. PM is positively and directly related to PS.
H1j	QM is positively and directly related to QY.	H2k H2l H2m H2n	QM is positively and directly related to CF. QM is positively and directly related to QG. QM is positively and directly related to EI. QM is positively and directly related to PS.
H1k H1l	ET is positively and directly related to EM. ET is positively and directly related to PD.	H2o H2p	ET is positively and directly related to EI. ET is positively and directly related to CF.
H1m H1n H1o	FI is positively and directly related to QY. FI is positively and directly related to PD. FI is positively and directly related to PF.	H2q H2r H2s	FI is positively and directly related to SP. FI is positively and directly related to CL. FI is positively and directly related to PS.
H1p	HS is positively and directly related to SH.		

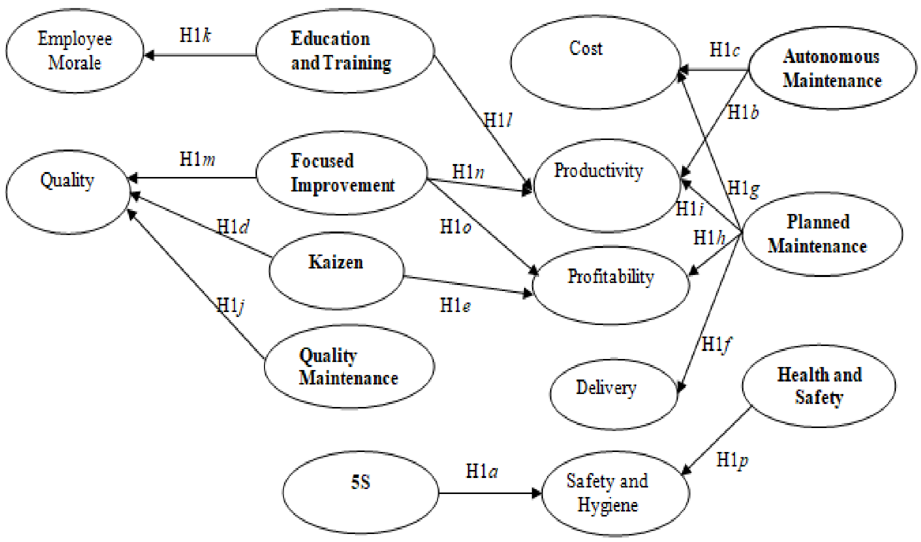

Figure 1. The developed structural model I.

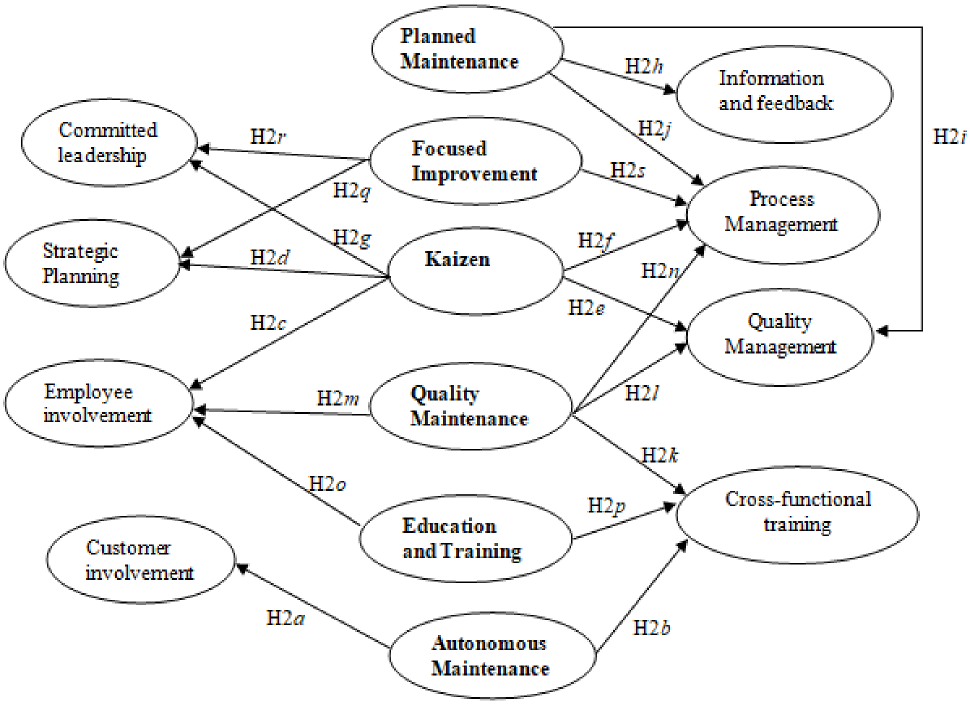

Figure 2. Developed hypotheses of Model II.

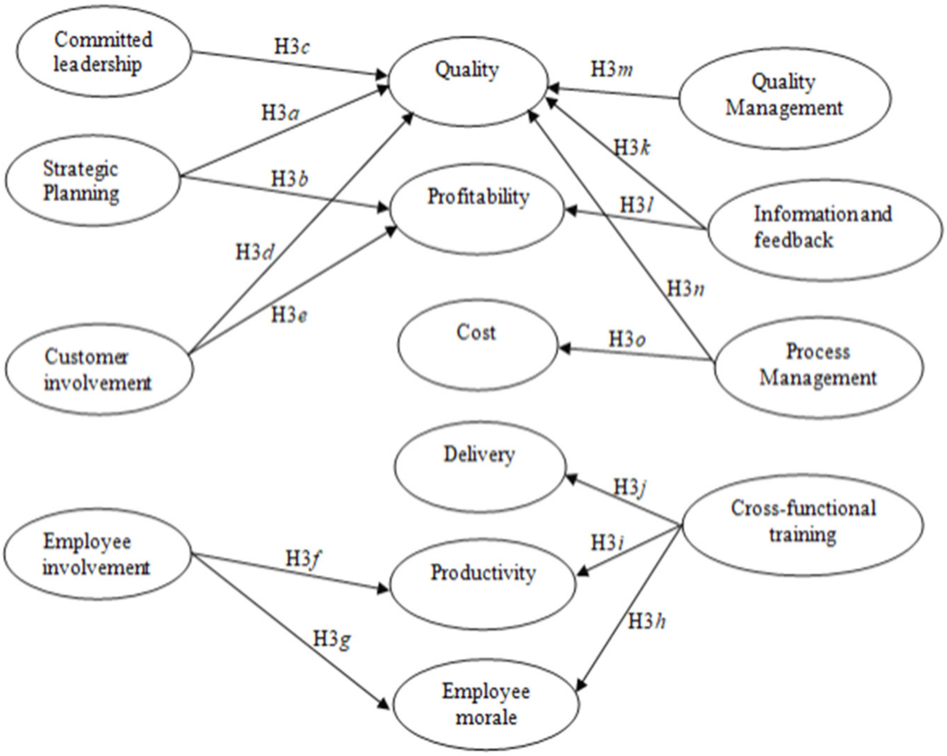

Figure 3. Proposed hypotheses of Model III.

Table 5. Hypotheses relating TQM to MPR.

Pillar	Hypothesis	
SP	H3a H3b	SP is positively and directly related to QY. SP is positively and directly related to PF.
CL	H3c	CL is positively and directly related to QY.
CI	H3d H3e	CI is positively and directly related to QY. CI is positively and directly related to PF.
EI	H3f H3g	EI is positively and directly related to PD. EI is positively and directly related to EM.
CF	H3h H3i H3j	CF is positively and directly related to EM. CF is positively and directly related to PD. CF is positively and directly related to DY.
IF	H3k H3l	IF is positively and directly related to QY. IF is positively and directly related to PF.
QG	H3m	QG is positively and directly related to QY.
PS	H3n H3o	PS is positively and directly related to QY. PS is positively and directly related to CT.

2.5. Survey Development and Analysis

The survey consists of two parts. Part one concerns the demographic aspects: type, age, size, status of ISO certification, and maintenance approaches used. The second part is intended to assess the TPM, TQM, and MPR pillars. A five-point Likert scale (1: Strongly disagree, 2: Disagree, 3: Neutral, 4: Agree, and 5: Strongly agree) was adopted to evaluate the item measures of the TPM and TQM pillars and performance. A pilot study was performed to assess the appropriateness of the pillars, relationships, and item measures by quality and maintenance managers and experts in the industrial domain. Fifty surveys were then distributed to industrial firms in personal site visits and via emails. Out of fifty, thirty completed surveys were received, which amounts to a response rate of 60%. The results of the parts of the survey related to the general and structural aspects of firms and the TPM and TQM pillars showed that:

- The age of the majority of the responding firms (59%) is between 11 to 20 years.
- The number of employees of the majority (=31%) of responding firms corresponds to those that exceed 200 employees and have between 10 to 50 employees.
- The majority (=53%) of responding firms have implemented TPM practices, whereas 2% of the firms have relied on corrective maintenance.
- The maintenance team of the majority of firms (=38%) is composed of one to five technicians.
- About 61 % of the responding firms received ISO 9001 registration.

Table 6 displays the means, standard deviations (Std. dev.), and coefficient of variation (COV) values for each pillar, and it is obvious that there is significant dispersion around the mean of each pillar's responses, because all the values of the coefficients of variation are larger than 5%. For the TPM pillars, the large COV values, i.e., greater than 20%, correspond to PM (=27.57%), QM (=29.60%), HS (=20.73%), and FI (=22.45%). The lowest mean value (<3.00) corresponds to QM (=2.3103). The largest mean value (=3.7655) corresponds to 5S. Further, for the TQM pillars, the largest COV values correspond to IF (=24.30%), PS (=21.15%), and SP (=20.68%). Meanwhile, the lowest mean values correspond to information and feedback (=2.8897). The largest mean (=3.9138) corresponds to quality management (QG). Finally, for the pillars of MPR, the largest COV values correspond to PF (=24.12%), SH (=21.86%), and EM (=20.39). None of the mean values is less than 3.00. The largest mean values correspond to a quality (QY) and delivery (DY) of 3.8138 and 3.8276, respectively. To test the hypothesis that the mean is larger than 3, the z values are calculated and then displayed in Table 6. It is noted that the means of QM, FI, and

IF are not significantly larger than 3. Next, the one-way analysis of variance (ANOVA) technique is used to decide whether the pillars' estimated means for each of TPM, TQM, and MPR are equal or not. The results are shown in Table 7, where it is found that the estimated pillar means are significantly different for TPM, TQM, and MPR. That is, the degree of implementation for the TPM, TQM, and MPR pillars varies significantly among the responding firms.

Table 6. Descriptive analysis of the collected responses for each pillar.

Latent	Pillar	N	Mean	Std. dev.	Coefficient of Variation	z-Value (z Cirital = 1.6)	Significance
TPM	5S	29	3.7655	0.4474	11.88%	9.21	Significant
	AM	29	3.5793	0.4254	11.89%	7.33	Significant
	KA	29	3.3793	0.6024	17.83%	3.39	Significant
	PM	29	3.3596	0.9263	27.57%	2.09	Significant
	QM	29	2.3103	0.6839	29.60%	−5.43	Insignificant
	ET	29	3.5776	0.5432	15.18%	5.73	Significant
	HS	29	3.3851	0.7016	20.73%	2.96	Significant
	FI	29	3.0259	0.6792	22.45%	0.21	Insignificant
TQM	SP	29	3.6207	0.7489	20.68%	4.46	Significant
	CL	29	3.5747	0.6035	16.88%	5.13	Significant
	CI	29	3.5862	0.7163	19.97%	4.41	Significant
	EI	29	3.4345	0.6025	17.54%	3.88	Significant
	CF	29	3.3621	0.4461	13.27%	4.37	Significant
	IF	29	2.8897	0.7022	24.30%	−0.85	Insignificant
	QG	29	3.9138	0.4784	12.22%	10.29	Significant
	PS	29	3.4897	0.7379	21.15%	3.57	Significant
MPR	CT	29	3.2759	0.6063	18.51%	2.45	Significant
	QY	29	3.8138	0.4033	10.57%	10.87	Significant
	DY	29	3.8276	0.6148	16.06%	7.25	Significant
	PF	29	3.5086	0.8464	24.12%	3.24	Significant
	PD	29	3.4828	0.5605	16.09%	4.64	Significant
	SH	29	3.6897	0.8064	21.86%	4.61	Significant
	EM	29	3.6552	0.7453	20.39%	4.73	Significant

Table 7. ANOVA for the responses of TPM, TQM, and MPR.

Latent	Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	*p*-Value
TPM	Pillars	7	41.858	5.980	<0.001
	Error	224	92.920		
	Total	231	134.778		
TQM	Pillars	7	17.188	2.455	<0.001
	Error	224	91.472	0.408	
	Total	231	108.659		
MPR	Pillars	6	6.825	1.137	0.022
	Error	196	88.046	0.449	
	Total	202	94.871		

2.6. Models' Content Validity

To examine the validity of the models, three popular tests will be used: The test for multicollinearity between the items, the test of the reliability of the measurement variables, and the convergent and discriminant validities.

(i) Multicollinearity. Multicollinearity assesses the degree by which an item measures the same entity; a value of 0.90 or above implies the possibility that two or more items measure the same entity. Table 8 displays a sample of the inter-item correlation matrix.

It is observed that none of the inter-item correlation values exceed 0.9, and hence the multicollinearity problem does not present itself.

(ii) Test of reliability. The Cronbach's alpha, α, assesses the internal consistency between the item measures of each pillar. Generally, a Cronbach's α value larger than 0.6 implies internal consistency in the item measures. Table 9 displays the obtained α values for all pillars, where the obtained α values reflect a high reliability.

(iii) Convergent and Discriminant Validity. Convergent validity assesses whether varying approaches to the measurement of pillars yield the same results, whereas discriminant validity checks whether the items estimate only the assigned pillar and not others. The confirmatory factor analysis model is a structural equation modeling technique where the constructs are all co-varied with each other, and the goodness-of fit of this model is analyzed using various indices, including: (1) Goodness of fit (GFI) are absolute indices of fit which basically compare the hypothesized model with no model at all. Both indexes range from zero to 1.00, with values close to 1.00 being indicative of good fit, (2) The goodness of fit index (GFI) and adjusted goodness of fit index (AGFI), with values range from zero to 1.00, where values close to 1.00 indicate good fit, and (3) Root mean square for residuals (RMR) represents the average residuals value derived from the fitting of the variance–covariance matrix for the hypothesized model to the variance–covariance matrix of the sample data. The standardized RMR value ranges from zero to 1.00; in a well-fitted model, and this value is at most 0.05. Table 10 lists the calculated values of GFI, AGFI, and RMR for each model, where the calculated GFI, AGFI, and RMR indices indicate the convergent and discriminant validities of the three models.

Table 8. Sample of inter-item correlation matrix.

	CT-1	CT-3	QY-1	QY-2	QY-5	DY-2	PF-3	PF-4	PD-2	PD-3
CT-1	1	0.429	0.232	0.289	0.324	0.463	0.082	0.231	0.030	0.221
CT-3	0.143	1	0.287	0.376	0.129	0.039	0.224	0.312	0.331	0.460
QY-1	0.266	0.003	1	0.288	0.265	0.322	0.293	0.056	0.034	0.050
QY-2	0.531	0.229	0.053	1	0.344	0.336	0.467	0.408	0.097	0.260
SP-2	0.243	0.331	0.397	0.222	0.256	0.033	0.057	0.052	0.209	0.442
PS-4	0.233	0.412	0.260	0.444	0.448	0.094	0.265	0.032	0.214	0.312
CL-3	0.322	0.239	0.150	0.409	0.052	0.200	0.448	0.353	0.253	0.036
CI-4	0.475	0.327	0.288	0.244	0.223	0.032	0.224	0.243	0.434	0.308
EI-2	0.264	0.196	0.465	0.052	0.210	0.448	0.239	0.196	0.429	0.052
CF-3	0.361	0.229	0.032	0.224	0.312	0.336	0.327	0.229	0.022	0.424
IF-5	0.229	0.032	0.232	0.312	0.336	0.467	0.229	0.032	0.264	0.312
QG-2	0.355	0.143	0.244	0.056	0.033	0.057	0.331	0.353	0.293	0.056

Table 9. Results of Cronbach's α values.

TPM		TQM		MPR	
Pillar	**α Value**	**Pillar**	**α VALUE**	**Pillar**	**α Value**
5S	0.7340	SP	0.7257	CT	0.8990
AM	0.8532	CL	0.7640	QY	0.7494
KA	0.9330	CI	0.9303	DY	0.8454
PM	0.8718	EI	0.8770	PD	0.8805
QM	0.8920	CF	0.6020	SH	0.7350
ET	0.7809	IF	0.7270	PF	0.8200
HS	0.7200	QG	0.9570		
FI	0.8820	PS	0.8333		

Table 10. Estimated GFI, AGFI, and RMR values for the three models.

Models	Type	GFI	AGFI	RMR
Model I	Measurement	0.937	0.924	0.037
	Structural	0.894	0.887	0.043
Model II	Measurement	0.922	0.910	0.051
	Structural	0.917	0.902	0.029
Model III	Measurement	0.941	0.924	0.012
	Structural	0.933	0.908	0.048

As a result, the three structural models can be further examined to draw reliable conclusions regarding the significance of the relationships between the pillars of TPM, TQM, and MPR.

3. Results and Discussion

Tables 11–13 present the obtained results of Model I to III, respectively, where it is noticed that:

- In Table 11 for the relationships between the pillars of TPM and MPR (Model I), it is noticed that the largest weight (=3.2430) corresponds to the impact of planned maintenance (PM) on profitability (PF), whereas the smallest weight (=0.0664) corresponds to the impact of focused improvement (FI) on quality (QY). The largest weights of AM, KA, PM, ET, and FI correspond to CT (=0.2100), QY (=1.3080), PF (=3.2430), PD (=0.3570), and PD (=1.1020), respectively. Moreover, all the relationships are supported (p value less than 0.05), except for the hypothesized relationships H1c: AM→CT and H2k: ET→EM. In other words, autonomous maintenance (AM) and employee training (ET) do not have significant positive effects on cost (CT) and employee morale (EM), respectively. This indicates that machine operators lack the necessary training and skills on how to maintain machines, and thereby no significant cost reduction is achieved. Another point to highlight, based on responding firms' responses, is that management only focuses on the reduction in production costs and does not encourage operators (employee) training on performing maintenance tasks, which results in a low overall employee satisfaction and team spirit.
- In Table 12, for the relationships between the pillars of TPM and TQM (Model II), it is shown that the largest weight (=2.5000) corresponds to the impact of Kaizen (KA) on committed leadership (CL), whereas the smallest weight (=0.3155) corresponds to the influence of employee training (ET) on cross-functional training (CF). The largest weights of AM, KA, PM, QM, ET, and FI correspond to EI (=0.4770), CL (=2.5000), QG (=1.8190), CF (=1.2350), EI (=1.2920), and CL (=2.2100), respectively. In addition, all the hypothesized positive relationships are significant except for the relationships H2e: KA→QG, H2g: KA→CL, and H2r: FI→CL. In other words, Kaizen (KA) has no significant direct and positive relationships with quality management (QG) and committed leadership (CL), while focused improvement (FI) does not significantly impact CL. These results imply that firms do not regularly evaluate and implement employees' suggestions and encourage all employees to participate in continual improvements. It is found that top management is only committed to improving quality and provides employees with the necessary leadership to produce quality products and achieve quality improvements. This means that KA has no significant direct and positive relationship with QG. On the other hand, the results showed that management is not fully committed to maintenance improvement, pays less attention to the reduction of maintenance costs and equipment losses, and seldom benchmarks maintenance performance. Due to these reasons, the influences of KA and FI on CL are shown to be insignificant.

Table 11. Results of Model I (TPM→ MPR).

Pillar	H1	Relationship			Weight	*p*-Value	Decision
5S	H1a	5S	→	SH	1.2230	<000.1	Supported
AM	H1b	AM	→	PD	0.1060	<000.1	Supported
	H1c	AM	→	CT	0.2100	0.400	Not Supported
KA	H1d	KA	→	QY	1.3080	<000.1	Supported
	H1e	KA	→	PF	1.0450	<000.1	Supported
PM	H1f	PM	→	DY	1.4160	<000.1	Supported
	H1g	PM	→	CT	1.8190	<000.1	Supported
	H1h	PM	→	PF	3.2430	<000.1	Supported
	H1i	PM	→	PD	1.9540	<000.1	Supported
QM	H1j	QM	→	QY	1.2350	<000.1	Supported
ET	H1k	ET	→	EM	0.3130	0.0570	Not Supported
	H1l	ET	→	PD	0.3570	0.0380	Supported
FI	H1m	FI	→	QY	0.0664	<000.1	Supported
	H1n	FI	→	PD	1.1020	<000.1	Supported
	H1o	FI	→	PF	0.7850	<000.1	Supported
HS	H1p	HS	→	SH	1.3900	<000.1	Supported

Table 12. Results of Model II (TPM→ TQM).

Pillar	H2	Relationship			Weight	*p*-Value	Decision
AM	H2a	AM	→	EI	0.4770	<0.001	Supported
	H2b	AM	→	CF	0.1090	<0.001	Supported
KA	H2c	KA	→	EI	1.7650	<0.001	Supported
	H2d	KA	→	SP	1.5490	<0.001	Supported
	H2e	KA	→	QG	2.2250	0.350	Not Supported
	H2f	KA	→	PS	2.4020	<0.001	Supported
	H2g	KA	→	CL	2.5000	0.9900	Not Supported
PM	H2h	PM	→	IF	1.4600	<0.001	Supported
	H2i	PM	→	QG	1.8190	<0.001	Supported
	H2j	PM	→	PS	1.3155	<0.001	Supported
QM	H2k	QM	→	CF	1.2350	<0.001	Supported
	H2l	QM	→	QG	0.5630	<0.001	Supported
	H2m	QM	→	EI	0.5310	<0.001	Supported
	H2n	QM	→	PS	0.9330	<0.001	Supported
ET	H2o	ET	→	EI	1.2920	<0.001	Supported
	H2p	ET	→	CF	0.3155	<0.001	Supported
FI	H2q	FI	→	SP	0.9930	<0.001	Supported
	H2r	FI	→	CL	2.2100	<0.780	Not Supported
	H2s	FI	→	PS	0.9970	<0.001	Supported

- In Table 13, for the relationships between the pillars of TQM and MPR (Model III), it is seen that the largest weight (=0.8317) corresponds to the impact of quality management (QG) on quality (QY), whereas the smallest weight (=0.1130) corresponds to the influence of employee involvement (EI) on productivity (DY). The largest weights of SP, CI, EI, CF, IF, and PS correspond to PF (=0.7860), PF (=0.5850), EM (=0.1500), EM (=0.5580), QY (=0.5580), and CT (=0.4050), respectively. Further, all the relationships are significant except for the relationships H3b: SP→PF, H3e: CI→PF, H3i: CF→PD, and H3j: CF→DY. That is, there is no significant direct and positive effect of strategic planning (SP) and customer involvement (CI) on profitability (PF). Besides, the effects of cross-functional training (CF) on productivity (PD) and delivery (DY) are insignificant. These findings imply that although a firm develops a formal strategic planning process and makes its vision on quality improvements, top management neither routinely review and update a long-range strategic plan nor effectively communicate the corresponding mission statement throughout the firm. In addition, according to the respondents' responses, less attention is paid to enhancing the responsiveness to the customers' needs, assessing feedback quality and delivery performance, and forming teams to solve quality problems. In practice, ineffective SP, CI, and MPR assessment hinder the use of the latest technology and focus on profitable products that increase the market share. Moreover, cross-functional training (CF) and on-job learning do not lead to a significant reduction in the average lead-time or an increase in the percentage of the on-time deliveries of the right items and the right quantities.

Table 13. Results of Model III (TQM→ MPR).

Pillar	H3	Relationship			Weight	*p*-Value	Decision
SP	H3a	SP	→	QY	0.2010	0.005	Supported
	H3b	SP	→	PF	0.7860	0.643	Not Supported
CL	H3c	CL	→	QY	0.5830	0.002	Supported
CI	H3d	CI	→	QY	0.1440	0.044	Supported
	H3e	CI	→	PF	0.5850	0.748	Not Supported
EI	H3f	EI	→	PD	0.1130	0.021	Supported
	H3g	EI	→	EM	0.1500	0.045	Supported
CF	H3h	CF	→	EM	0.5580	0.011	Supported
	H3i	CF	→	PD	0.3100	0.450	Not Supported
	H3j	CF	→	DY	0.259	0.230	Not Supported
IF	H3k	IF	→	QY	0.5834	0.039	Supported
	H3l	IF	→	PF	0.3650	0.019	Supported
QG	H3m	QG	→	QY	0.8317	0.001	Supported
PS	H3n	PS	→	QY	0.1620	0.014	Supported
	H3o	PS	→	CT	0.4050	0.002	Supported

Further, the weights of indirect relationships between TPM and MPR through TQM are estimated and then listed in Table 14. For example, the impact (FI→CL→QY = 1.288430) of FI through the CL pillar on quality (QY) is estimated by multiplying the weight of FI→CL by the weight of CL→QY. Similarly, all the other weights of the indirect relationships are calculated. From Table 14, the following results are obtained:

- TPM pillars result in a larger increase in all MPR pillars than TQM, except for employee morale (EM). Further, the largest impact (=2.5051) of the TQM pillars corresponds to quality (QY). However, the smallest impact (=0.2590) corresponds to delivery (DY). Furthermore, the largest and smallest impacts of TPM correspond to a profitability (PF) and delivery of 5.0730 and 0.3130, respectively. Finally, the largest and smallest indirect impacts of TPM through TQM correspond to a quality (QY) and delivery of 8.855173 and 0.081715, respectively.
- For the quality (QY) pillar, the total of TPM→QY, TQM→QY, and TPM→TQM→QY impacts are calculated and found to be 2.5051, 2.6094, and 8.855173, respectively. It is noticed that both TPM and TQM have almost the same direct impact on QY. Nevertheless, the largest impact (=8.855173) on QY is through TQM. The total direct and indirect impact of the TPM pillars on QY is 11.46457, which is almost equal to the total impact (=11.36027) of the TQM pillars plus the impacts of TPM on QY through TQM. Finally, the overall impact of the TPM and TQM pillars is 13.96967. This result implies that implementing both TQM and TPM results in a larger improvement in quality than implementing TQM or TPM separately, while TPM better supports quality through TQM.

- For the profitability (PF) pillar, the direct impact (=5.0730) of TPM→PF is larger than that gained by TQM→PF (=1.7360) and TPM→TQM→PF (=2.530912).
- For the productivity (PD) pillar, the largest impact (=1.359702) corresponds to TPM→PF, whereas the smallest impact (=0.423) corresponds to TQM→PF.
- For the employee morale (EM) pillar, the largest impact (=3.5190) corresponds to TPM→TQM→EM, but the smallest impact (=0.708) corresponds to TQM→EM.
- For the delivery (DY) pillar, the largest impact (=1.4160) corresponds to TPM→DY, whereas the smallest impact (=0.081715) corresponds to ET→CF→DY.
- For the cost (CT) pillar, the largest impact (=2.0290) corresponds to TPM→CT, whereas the smallest impact (=0.4050) corresponds to PS→CT.
- For the safety and hygiene (SH) pillar, only the TPM→MPR relationship contributes to improving SH by 2.6130.

Table 14. Estimated impact of TPM and TQM on MPR.

Performance	TQM (1)	TPM (2)	TPM→TQM→ Performance (3)	(4) = (2)+(3)	(5) = (4) + (1)
QY	2.5051	2.6094	8.855173	11.46457	13.96967
PF	1.7360	5.0730	2.530912	7.603912	9.339912
PD	0.4230	3.5190	0.875985	4.394985	4.817985
EM	0.7080	0.3130	1.359702	1.672702	2.380702
DY	0.2590	1.4160	0.081715	1.497715	1.756715
CT	0.4050	2.0290	2.287238	4.316238	4.721238
SH		2.6130		2.613000	2.613000

In practice, the obtained results can guide top management in industrial Jordanian firms on the main pillars of TPM and TQM that enhance a specific MPR pillar. In sum, despite the direct positive relationships between the TQM and MPR pillars, it is concluded that the responding Jordanian firms believe that the direct and indirect implementation of the TPM pillars improve their MPR more than the TQM pillars.

4. Conclusions and Future Research

This research examines the relationships between the pillars of TPM, TQM, and MPR using structural equation modeling. Three structural models (I to III) were proposed to examine the direct relationships between the pillars of TPM and MPR, the indirect relationships between TPM and MPR through TQM, and the direct relationships between the pillars of TQM and MPR, respectively. The data were collected from thirty industrial firms, of which a high percentage has implemented TPM and TQM practices. The results of structural model I revealed that autonomous maintenance and employee training have insignificant effects on cost and employee morale. Further results of model II revealed that Kaizen has insignificant direct and positive relationships with quality management and committed leadership, while focused improvement insignificantly impacts committed leadership. Finally, the results of Model III showed that there is no significant direct and positive effect of strategic planning and customer involvement on profitability. A detailed analysis is also conducted to identify the most influential TPM and TQM on each of the MPR pillars. It is found that the implementation of TPM pillars provided larger impacts on almost all manufacturing performance pillars than TQM. Meanwhile, the TPM pillars also indirectly influence MPR through TQM. In conclusion, the research results shall guide top management on the main TPM and TQM pillars that significantly enhance the performance of industrial Jordanian firms.

Future research should consider developing an interpretive structural model that displays the hierarchy of the TPM and TQM pillars and manufacturing performance. One of the limitations of this research was the small size of the data.

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Nomenclature

Abbreviation	**Detail**
AGFI	Adjusted goodness of fit index
ANOVA	Analysis of variance
AM	Autonomous maintenance
CI	Customer involvement
CF	Cross-functional training
CL	Committed leadership
COV	Coefficient of variation
CT	Cost
DY	Delivery
EI	Employee involvement
EM	Employee morale
ET	Education and training
FI	Focused improvement
GFI	Goodness of Fit
GFI	Goodness of fit index
HS	Health and safety
KA	Kaizen
MPR	Manufacturing performance
PD	Productivity
PF	Profitability
PM	Planned maintenance
PS	Process management
QG	Quality management
QM	quality maintenance
QY	Quality
RMR	Root Mean square for Residuals
Std. dev	Standard deviations
SH	Safety and hygiene
SP	Strategic planning
TPM	Total productive maintenance
TQM	Total quality management

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