The relationships between TQM, TPM, JIT and agile manufacturing: an empirical study in industrial companies

Meriem Khalfallah
Ecole Supérieure des Sciences et de la Technologie de Hammam Sousse, Université de Sousse, Hammam Sousse, Tunisia, and
Lassaad Lakhal
Faculté des Sciences Economiques et de Gestion de Sousse, Université de Sousse, Sousse, Tunisia

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Abstract

Purpose – This empirical study aims to explore the relationship between Total quality management (TQM), Total productive/preventive maintenance (TPM) and Just-in time (JIT). It also seeks to examine the relationship between Just-in time (JIT) and agile manufacturing.

Design/methodology/approach – Data for the study were collected from a survey of 205 industrial companies and the relationships proposed in the framework were tested using structural equation modeling.

Findings – The results indicate that (1) TPM has a positive impact on TQM and JIT, (2) TQM has a positive effect on JIT and (3) JIT has a direct positive relationship with agile manufacturing. In addition, the results reveal an indirect effect of TPM and TQM on agile manufacturing through JIT.

Research limitations/implications – The conceptual model proposed and tested in this study can be used by researchers for developing Lean manufacturing practices (TQM, TPM and JIT) and agile manufacturing theory. In addition, this model shows to practitioners the importance of integrating TQM, TPM and JIT in manufacturing firms. In other words, this study shows practitioners how firms can support their agile manufacturing system.

Originality/value – This research presents an innovative approach since it examines simultaneously the interdependencies between TQM, TPM and JIT and their direct and indirect link with agile manufacturing using structural equation modeling.

Keywords Total quality management, Total productive maintenance, Just-in time, Agile manufacturing

Paper type Research paper

1. Introduction

In today's competitive and uncertain business environment, firms strive to gain competitive advantage by enhancing their business processes. Against this new dynamic and unpredictable background, many organizations have started to use agile manufacturing practices. There is an increasing recognition that agile manufacturing (AM) is an essential condition for firms' survival and competitiveness (Yusuf *et al.*, 1999; Sharifi and Zhang, 1999; Charbonnier-vorin, 2011; Gunasekaran *et al.*, 2019). The concept of agile manufacturing has been developed as a result of intense competition and environment change (Goldman and Nagel, 1993; Sharifi and Zhang, 1999; Yusuf *et al.*, 1999; Yusuf and Adeleye, 2002). Many manufacturers have adopted agile manufacturing practices in order to deal with highly-turbulent and uncertain environments (Charbonnier-vorin, 2011). Agile manufacturing is the organization's ability to adapt continuously and rapidly to environment changes (Gunasekaran, 1999; Yusuf *et al.*, 1999; Breu *et al.*, 2001; Charbonnier-vorin, 2011).

Although agile manufacturing was often presented as a means of improving companies' competitiveness and performance, few empirical studies have explored the principal levers of

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agile manufacturing. Most current studies have focused mainly on the environment turbulence (Vazquez-Bustelo *et al.*, 2007) or on the company's strategy (Hallgren and olhager, 2009; Charbonnier-vorin, 2011) as levers of agile manufacturing. However, it is important to study the effect of its antecedents, namely the practices of lean manufacturing (LM). Just-in time (JIT) is identified as one of the four important lean manufacturing bundles (Shah and Ward, 2003) which are generally recognized as a precursor to agile manufacturing (Narasimhan *et al.*, 2006; Inman *et al.*, 2011). Some studies showed that JIT has a significant effect on agile manufacturing (Inman *et al.*, 2011; Zelbst *et al.*, 2010). In contrast, other studies showed that JIT has insignificant direct effect on agile manufacturing (Iqbal *et al.*, 2018). Therefore, some authors suggest that successful implementation of JIT can be achieved only with the implementation of Total productive/preventive maintenance (TPM) practices and Total quality management (TQM) practices (McKone *et al.*, 2001).

So far, many important questions have recently been raised in the field of manufacturing practices theory. In our study, we have focused on the two following research questions:

RQ1. How are lean manufacturing practices (TPM, TQM and JIT) interrelated?

RQ2. What is the nature of the relationship between JIT and agile manufacturing?

The purpose of this paper is, therefore, to empirically test a framework identifying the relationships among TPM, TQM, JIT and agile manufacturing. A survey of Tunisian manufacturing firms is conducted in order to obtain data to assess the model. Structural equation methodology is used to test the hypothesized relationships. The remainder of this paper is organized as follows. Section 2 analyzes the related theoretical background and develops the hypotheses. Section 3 presents the research methodology and statistical outcome. Finally, discussion of the findings and conclusion of this research are presented.

2. Theoretical background and hypotheses

JIT is identified as one of the four important lean manufacturing bundles (Shah and Ward, 2003). It is "one of the main facets of lean manufacturing" (Furlan *et al.*, 2011). Therefore, in order to explain the relationship between JIT and agile manufacturing, existent literature suggests that it is relevant to relate lean manufacturing to agile manufacturing (Inman *et al.*, 2011). The relationship between lean manufacturing and agile manufacturing has been addressed in the literature from various perspectives. Recent studies support the view that lean manufacturing must be a precursor to agile manufacturing (Narasimhan *et al.*, 2006; Inman *et al.*, 2011; Iqbal *et al.*, 2018).

Agile manufacturing is viewed as the "next logical step" or a "natural development" from the existing system (Gunasekaran, 1999; Inman *et al.*, 2011) like lean production (JIT) (Hormozi, 2001). Jin-Hai *et al.* (2003) argue that agile manufacturing is generally recognized as an advanced stage of lean manufacturing.

Lean manufacturing practices (JIT, TQM and TPM) are generally presented as factors that help to promote agile manufacturing. Literature review supports the positive impact of lean manufacturing practices (JIT or TQM) on agile manufacturing (Zelbst *et al.*, 2010; Inman *et al.*, 2011; Iqbal *et al.*, 2018). And it reveals also that there exists a certain complementarity between these practices (JIT, TQM and TPM) (Cua *et al.*, 2001; McKone *et al.*, 2001; Abdallah and Matsui, 2007) which can lead to different effects on agile manufacturing and on the firm's performance (Cua *et al.*, 2001; Sakakibara *et al.*, 1997).

Few empirical studies have investigated the link between lean manufacturing practices (JIT, TQM and TPM) and how they can support each other (McKone *et al.*, 2001; Abdallah and Matsui, 2007). In addition, although this link has been rarely studied in the literature review, no recent studies have tried to develop more this relationship.

Thus, the present paper proposes to investigate the relationships between JIT and agile manufacturing as well as the link between TPM, TQM and JIT.

The theoretical model is presented in Figure 1.

2.1 TPM and JIT

TPM is a set of practice intended to maximize equipment effectiveness (Ahuja and Khamba., 2008 a, b; Sharma *et al.*, 2018) through using maintenance optimization techniques and planned total predictive and preventive maintenance of the equipment (Shah and Ward, 2003, 2007). It is based on the notion of "zero loss", that is zero accident, zero breakdowns and zero defects (Ahuja and Khamba, 2008a, b; Modgil and Sharma, 2016). Therefore, TPM helps to achieve a high level of equipment availability (Shah and ward, 2007; Sharma *et al.*, 2018).

The main purpose of JIT-production is waste reduction. Excess of inventories and extremely large lot sizes, long cycle times are considered as the main source of waste (McKone *et al.*, 2001; Flynn *et al.*, 1995a, b; Abdallah and Matsui, 2007). Thus, the highest level of JIT-production is when the company achieves zero inventory policy. The objective will be to respect the daily schedules and to maintain the cycle time as short as possible. The failure to meet daily schedules may result in delays in the delivery of customer orders and thus could lead to the reappearance of work in-process stocks. In this environment, unexpected machine breakdowns or downtime could seriously compromise production. Hence, the implementation of TPM can improve the smoothness of production and the turnover inventory rate. (Abdallah and Matsui, 2007). TPM practices are expected to have an essential role in reducing inventory and cycle time by preventing sudden stoppage and breakdown of equipment (McKone *et al.*, 2001; Abdallah and Matsui, 2007). Successful JIT implementation can be achieved only with a high level of equipment availability and effectiveness. TPM is the most adequate system which may ensure the required availability and reliability of the equipment (McKone *et al.*, 2001; Modgil, and Sharma, 2016; Sharma *et al.*, 2018).

The literature review supports the positive relation between TPM and JIT. Abdallah and Matsui (2007) found that TPM influences positively and facilitate the implementation level of JIT. McKone *et al.* (2001) findings reveal that TPM helps to improve the equipment performance which in turn supports JIT practices.

According to what precedes, we can state the following hypothesis:

H1. TPM is positively associated with JIT

2.2 TPM and TQM

The relationship between TPM and TQM has been scarcely studied. To explain this relationship, the authors focused first on identifying the similarities between TQM and TPM in order to justify the complementarity that exists between these two practices.

TPM is used to control the equipment performance. It is considered as a comprehensive improvement drive based on the notion of zero production defects, zero accidents and zero breakdowns. Authors consider TPM as a practice that emerge from TQM's practices of zero

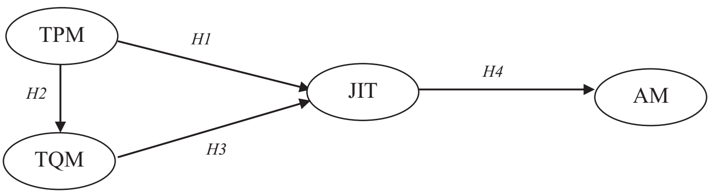

Figure 1.
Theoretical model

defects applied to equipments (Seth and Tripathi, 2006). Indeed, TQM and TPM have several similarities. Their practices focus mainly on the company performance such as quality, reduction of products defects (zero defects), reduction of costs and cycle time (Konecny and Thun, 2011), continuous improvement (Cooke, 2000), etc. Thus, several authors consider TQM and TPM as two complementary practices (Dale, 1999; Seth and Tripathi, 2006).

TQM is based on improving the product quality and processes. Its main objective is to reduce variation in the product and to eliminate defects. Successful TQM implementation can be achieved only with high level of equipment effectiveness, so TPM program is needed to provide reliable equipment maintenance and to reduce equipment process variation (McKone *et al.*, 2001).

Flynn *et al.* (1995a) state that the implementation of TPM improves the equipment effectiveness and increases the workers' skills, which could be an additional element in sustaining TQM.

Several studies confirm the complementarity that exists between TPM and TQM (Seth and Tripathi, 2006; Kaur, 2013; Singh and Ahuja, 2014, 2015). A review of the literature supports the positive bond between TPM and TQM. The theoretical study of Ahmad (2012) shows a positive correlation between TQM and TPM. Teeravaraprug *et al.* (2011) finding indicates that preventive maintenance is a necessary tool for the TQM implementation. McKone *et al.* (2001) have empirically found a significant positive effect of TPM on TQM.

The literature discussed above leads to the following hypotheses:

H2. TPM is positively associated with TQM.

2.3 TQM and JIT

As mentioned previously, the major objective of JIT-production is waste reduction. Excess of inventories, long cycle times are considered as the main source of waste. Hence, a successful implementation of JIT-production is when the company achieves zero inventory policy and maintains a shortened cycle time. Under such conditions, quality problems (manufacturing defect) can disrupt the production process (rejects and rework in the production process). Thus, the enterprise requires a high amount of safety stock inventory in order to compensate for the absence of a constant work flow and to meet customer needs (Flynn *et al.*, 1995a). In addition, quality problems (manufacturing defect) can disrupt the production process and thus extend the cycle time.

To achieve a high level of JIT it's necessary to ensure a high level of quality (zero defects). TQM is the most adequate system which may ensure the required quality. TQM is considered as "an umbrella" for a variety of methods and tool production (Ahmad, 2012). Juran (1999) reveals that TQM practices are a "fundamental pillars" for implementing Lean production practices (such as JIT). The role of TQM is widely recognized as being a critical determinant of quality performance; however it can be useful to support JIT practices. His contribution can be revealed on two principles.

TQM decreases rework by reducing the number of defective product and ensures thus a shortened cycle time (eliminating wasted time) (Flynn *et al.*, 1995a; Mefford, 1989).

JIT requires consistent and stable production. TQM practices such as Statistical Process Control (SPC) is a statistical method to predict and control the stability of production process (Besterfield, 2009). TQM practices reduce process variance (a less variable manufacturing process) through a better control of product quality that, in turn, reduces the need for safety stock inventory.

The literature review defends the positive relation between TQM and JIT. Flynn *et al.* (1995a) have empirically found that TQM practices contribute to ensure the levels of quality that permit production to proceed with minimum safety stock inventory. They concluded that TQM practices contribute to ensure the reduction of the cycle time by reducing the time required for rework of defective products and production of non-value-added products. They found a positive relationship between TQM practices and JIT.

This discussion leads to the following hypotheses:

H3. TQM is positively associated with JIT

2.4 JIT and agile manufacturing

The main goal of JIT practices is to reduce and eliminate waste. It is a global approach to continuous improvement based on the concept of eliminating waste (Sakakibara *et al.*, 1993) through simplification of manufacturing processes (Flynn *et al.*, 1995a, b). JIT-production is a set of methods and techniques which eliminate waste and inefficiency in the production process (Wisner *et al.*, 2005). There are many forms of waste, for example over production, excess inventories, scrap losses, material movements (unnecessary movement), production steps (long cycle time), rejects and rework in the production process (Womack *et al.*, 1990; Flynn *et al.*, 1995a, b; Brox and Fader, 2002; Wisner *et al.*, 2005; Inman *et al.*, 2011).

JIT-production attempts to adhere to daily schedules and to maintain the cycle time as short as possible. The main purpose of JIT is to provide products on time in order to respond rapidly to customer expectations and to increase the reactivity of the firm. Hence, it is considered as an organizational philosophy (Yasin *et al.*, 1997) that provides firms with speed and flexibility in order to meet global competition (Blackburn, 1991; Fullerton *et al.*, 2003). Such rapidity and flexibility are necessary to achieve an optimal level of agile manufacturing implementation. Indeed, as mentioned earlier, agile manufacturing is the ability of a firm to adapt quickly to environment changes (Yusuf *et al.*, 1999; Charbonnier-vorin, 2011). It is the capacity of a firm to survive and prosper in a turbulent and unpredictable environment by reacting effectively and rapidly to the market evolution (Gunasekaran, 1999). Such reactivity can be achieved only with the implementation of JIT practices.

Agile manufacturing is recognized as an advanced stage of lean manufacturing (Jin-Hai *et al.*, 2003; Gunasekaran *et al.*, 2019). It is a natural development from the original concept of lean manufacturing (Booth, 1996). As mentioned earlier, Shah and Ward (2003) identified JIT as one of four important lean manufacturing bundles. It is "one of the main facets of lean manufacturing" (Furlan *et al.*, 2011). Therefore, JIT is considered as a precursor to agile manufacturing (Vázquez Bustelo *et al.*, 2007; Inman *et al.*, 2011).

Literature review defends the positive link between JIT and agile manufacturing. Empirical evidence is available to support the relationship between JIT and agile manufacturing practices. Swink *et al.* (2005) found that manufacturing practices including JIT-flow moderated by strategy integration help improve new product flexibility. The main findings of Phan *et al.'s* (2019) study suggest that flexibility can be built up by implementing both TQM and JIT-production practices. Iqbal *et al.* (2020) empirically validated that lean manufacturing (JIT and TQM) and AM are complementary capabilities. Khalfallah and Lakhal (2020) results indicate that JIT-production has an indirect effect on agile manufacturing through JIT-purchasing and TQM. Inman *et al.* (2011) empirically validate the indirect impact of JIT-production on agile manufacturing through the JIT-purchasing. Iqbal *et al.* (2018) empirically found an indirect relationship between JIT and agile manufacturing through common external infrastructure (relationship with customers and suppliers). Gurahoo *et al.* (2018) found that lean implementation strategies (such as JIT practices) are required for agile manufacturing.

Therefore, we propose the following hypothesis:

H4. JIT is positively associated with agile manufacturing.

3. Research methodology

3.1 Data collection and sample

Data from a sample of manufacturing managers of Tunisian certified manufacturers were collected via a combination of direct contact with relevant managers and Internet-based survey methods. Company lists were obtained from the Tunisian Industry Portal (http://www.tunisianindustry.nat.tn). The data used in the current study were obtained from a questionnaire method (Appendix 1). Based on literature, managers who are at higher managerial levels were chosen as respondents for the current study. A total of 205 responses were returned and identified useable, yielding the effective response rate of 22.7%.

The sample of the study includes certified industrial companies with a variety of sectors (Electrical, Electronic and Appliance Industries, Mechanical and metallurgical industry, Chemical industry, Food industry, Ceramic and glass building materials industry, Wood and cork industries and Leather and footwear industries). Certified industrial companies were chosen because they are the most concerned with the use of TPM, JIT and agile manufacturing practices, and the choice of a varied sample permits the generalization of results and restricts the problem of the lack of information for some sectors.

3.2 Statistical techniques

The current study is confirmatory and the proposed framework to test the hypotheses is built on the basis of results of previous empirical studies conducted in manufacturing practices.

A Structural equation modeling (SEM) method will be used to test the causal relations presented in Figure 1. SEM is a statistical technique for estimating and testing causal relationships. SEM is more relevant in confirmatory studies than in exploratory studies. There are generally two principal parts of SEM: the measurement model demonstrates the relations between the latent variables and their indicators and the structural model demonstrate potential causal dependencies that exist between endogenous and exogenous variables (Gerbing and Anderson, 1988).

3.3 Measurement of constructs

The theorized model incorporates constructs related to TPM, JIT and agile manufacturing. The scales selected to measure the constructs were previously developed and assessed in prior studies. To measure JIT, we have opted for the scales used by Furlan *et al.* (2011). The TPM scale incorporates multiple dimensions; Autonomous and planned maintenance, Technology emphasis, Proprietary equipment development. This scale is taken from Cua *et al.* (2001). To measure TQM, we have opted for the scales developed by Choi and Eboch (1998). The agile manufacturing scale is taken from Inman *et al.* (2011). The same scales of measures (same items) were used to judge their applicability in our context.

Each respondent rated one's perception of the firm's practice on a five-point Likert scale (1 = "very low" to 5 = "very high").

4. Results for the measurement model

Quality measurement scales is established based on three steps: (1) unidimensionality analysis; (2) reliability analysis and (3) convergent and discriminant validity analysis (O'Leary-Kelly and Vokurka, 1998).

4.1 Unidimensionality analysis

Unidimensionality is indicated by root mean square error of approximation (RMSEA) below 0.08 (Garver and Mentzer, 1999), goodness-of-fit index (GFI) values greater than 0.90 (Pedhazur and Pedhazur Schmelkin, 1991), comparative-fit index (CFI) values and

Tucker–Lewis (TLI) coefficient greater than 0.90 (Garver and Mentzer, 1999). All scales met the RMSEA, CFI and TLI minimums indicating unidimensionality (Table 1).

All scales were treated as first-order factors, except TPM and TQM. To assess unidimensionality, TPM and TQM were treated as a second-order factors. Values for each of the three constructs of TPM and the four constructs of TQM were calculated by averaging across factor items, and then the factor values were used in the unidimensionality evaluation.

4.2 Reliability analysis

To assess reliability it is recommended to use Cronbach's index. This coefficient should be higher than 0.6 (Evrard *et al.*, 2003). Jöreskog *et al.* (1999) recommend computing Jöreskog's rhô (Jöreskog's ρ) of internal consistency to assess the scale reliability. Index should be greater than 0.70 (Fornell and Larker, 1981). The results are presented in Table 2.

4.3 Convergent and discriminant validity

The convergent validity analysis was verified according to the approach of Fornell and Larcker's (1981). The coefficient rhô of convergent validity should be greater than 0.50. The convergent validity of the scales used in this study was supported. Table 3 presents the results of these analyses.

Discriminant validity was assessed in two different ways.

Anderson and Gerbing (1988) recommended that discriminant validity can be assessed by comparing the constrained and the unconstrained model. Each pair of factor correlations is set to 1 in the constrained model. A significant chi-square difference between unconstrained model (a low value of chi-square in the unconstrained model) and constrained model indicates that factors have discriminant validity (Anderson and Gerbing, 1988). Discriminant validity is confirmed; the difference of the Chi-square for 1 degree of freedom is significant for all dimensions [e.g. ($\Delta\chi = 44.64$; $\Delta ddl = 1$; $p < 0.01$)].

The second method involves comparing the square root of the average variance extracted (AVE) with the corresponding factor correlations. The square root of the AVE for each

		Unidimensionality		
Scale	GFI	RMSEA	TLI	CFI
JIT	0.996	0.049	0.989	0.998
TPM	0.979	0.024	0.997	0.998
TQM	0.953	0.025	0.995	0.997
AM	0.969	0.071	0.972	0.986

Table 1. Measurement scale Unidimensionality results

Latent variables	Cronbach alpha	Jöreskog's ρ
JIT	0.798	0.801
TPM (Autonomous and planned maintenance)	0.905	0.902
TPM (Technology emphasis)	0.931	0.926
TPM (Proprietary equipment development)	0.800	0.897
TQM (Process quality)	0.842	0.828
TQM (Human resources)	0.919	0.881
TQM(Strategic quality planning)	0.947	0.909
TQM (Information and analysis)	0.925	0.977
AM	0.902	0.923

Table 2. Reliability coefficients

construct should be greater than the corresponding inter-construct correlations (Fornell and Larcker, 1981). The results are presented in Table A1.

5. Results of the structural model

After validating the scales, the conceptual model was evaluated. To test the hypotheses structural equation modeling using AMOS 18 was employed. Figure 2 represents the structural equations model in the set of concepts being studied. The model fit well with statistics; The RMSEA (0.03) is under the suggested maximum of 0.08 (Roussel *et al.*, 2002; Schumacker and Lomax, 1996). The relative chi-square (1.22) is below the recommended maximum of 3.00 (Pedhazur and Pedhazur Schmelkin, 1991). The CFI (0.958), TLI (0.953), NFI (0.889) meet or exceed the recommended level 0.90 (Bentler and Benett, 1980). The GFI (0.866) is slightly under the suggested level 0.90 (Bentler and Bonett, 1980). This index is very sensitive to the size of the sample (Byrne, 1998) and to the complexity degree of the model (Roussel, 2005). The threshold generally used for this index (GFI) is 0.9. However many authors have suggest different thresholds of 0.8 and 0.9, they reveal that the value of GFI greater than 0.9 indicates a very good fit, while value between 0.8 and 0.9 show a good fit (Mulaik *et al.*, 1989; Segars and Grover 1993; Hair *et al.*, 1998).

5.1 Direct effects

The results of the proposed structural equation model analysis are illustrated in Table 4 indicating support for all the hypotheses. The results support Hypothesis 1, which indicates that TPM is positively associated with JIT. The standardized coefficient is 0.29, which is statistically significant at $p < 0.05$ (CR = 2.243). We also found a positive and significant relationship between TPM and TQM; the standardized coefficient is 0.74 and $p < 0.01$ (C.R = 6.216). Therefore, H2 is supported. The relationship between TQM and JIT (H3) is statistically significant, with an estimate of 0.27 and $p < 0.05$ (C.R = 2.132). Thus, H3 is supported. Hypothesis 4, which states that JIT is positively associated with agile

Table 3. Rhô of convergent validity

Latent variables	Rhô of convergent validity
JIT	0.517
TPM (Autonomous and planned maintenance)	0.692
TPM (Technology emphasis)	0.807
TPM (Proprietary equipment development)	0.814
TQM (Process quality)	0.620
TQM (Human resources)	0.651
TQM (Strategic quality planning)	0.770
TQM (Information and analysis)	0.926
AM	0.635

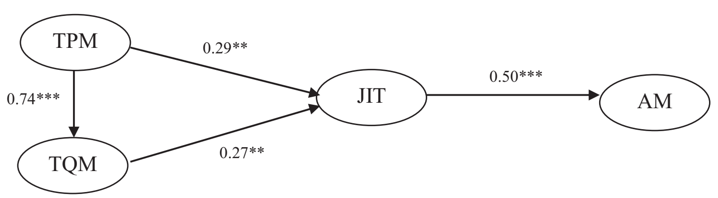

Figure 2. Model with the structural equation modeling results

manufacturing, is also supported. The standardized coefficient is 0.50, which is statistically significant at $p < 0.01$ (CR = 6.53).

5.2 Mediating effect

In the current model, it is also possible to analyze the indirect effects of TPM and TQM on agile manufacturing. The results showed significant indirect effects of TPM and TQM on agile manufacturing through JIT. Table 5 presents the results of indirect effects.

6. Discussion

Based on the literature review, the study assumed that TPM has a positive effect on JIT and TQM. Similarly, the results of the SEM support these positive relations. This result corroborates the studies of Abdallah and Matsui (2007); McKone *et al.* (2001) and Teeravaraprug *et al.* (2011). As previously stated Abdallah and Matsui (2007) found that TPM facilitate the implementation of JIT, their results show a positive impact of TPM on JIT. McKone *et al.* (2001) found that TPM helps to enhance the equipment performance which in turn supports JIT practices and TQM practices. Teeravaraprug *et al.* (2011) found that preventive maintenance is an essential tool for TQM implementation.

The literature review reveals that TQM has a positive impact on JIT. Similarly our results support this positive relation. This result corroborates the studies of Flynn *et al.* (1995a). As previously indicated, they empirically found a positive relationship between TQM practices and JIT.

The literature review indicates that JIT has a positive effect on agile manufacturing, as well. Our findings support this positive link. This finding is consistent with the studies of Gurahoo *et al.* (2018); Zelbst *et al.* (2010), Inman *et al.* (2011) and Iqbal *et al.* (2018). As previously mentioned the studies of Zelbst *et al.* (2010), Inman *et al.* (2011); Iqbal *et al.* (2018) have found a positive indirect effect of JIT on agile manufacturing. Gurahoo *et al.* (2018) have also found that lean implementation strategies (e.g. JIT practices) are required for agile manufacturing. In fact, JIT intends to provide products on time in order to meet the customer's requirements rapidly and to increase the flexibility and reactivity level of the firm. This allows companies to improve their agility. Therefore, JIT is considered as a lever for agile manufacturing that supports and facilitates the implementation and the development of agile manufacturing.

It was also found that TPM and TQM have an indirect effect on agile manufacturing through JIT. Indeed, Shah and Ward (2003) identified TPM and TQM as two of the four

Hypotheses	Paths (VID→VD)	(Estimate /Standardized regression weight)	C.R.	p
H1	TPM → JIT	0.294	2.243	**
H2	TPM → TQM	0.742	6.216	***
H3	TQM → JIT	0.272	2.132	**
H4	JIT → AM	0.509	6.534	***

Note(s): Significant at: ** p, 0.05 and *** p, 0.001 levels

Table 4. Direct effects results

Indirect relations	Standardized indirect effects
TPM and Agile manufacturing	0.149
TQM and Agile manufacturing	0.138

Table 5. Indirect effects of TPM and TQM on agile manufacturing trough JIT

practices (bundles) of lean manufacturing that is widely recognized as an enabler of agility (McCullen and Towill, 2001). Hence TPM and TQM may support agile manufacturing implementation and development. Indeed, agile manufacturing aims to meet customer requirements efficiently and quickly and provide customers with high quality products. TQM practices also seek continuous improvement in all functions of a company (zero defect, reduced variation, shortened cycle time, etc.) in order to improve product quality and meet customer requirements and expectation. In fact, TQM is considered as the most adequate system which may ensure the required quality and reactivity. Zelbest *et al.* (2010) reveal that TQM practices help manufactories to create an environment which can support agile manufacturing implementation/development. Agile manufacturing aims also to react rapidly and effectively to the market change and evolution. It is based on flexibility and reactivity which explains its sensitivity to the equipment breakdowns. Similarly, successful implementation of JIT and TQM can be attained only with high level of equipment availability and effectiveness. There, TPM is considered as the most adequate system which may ensure the required availability and reliability of the equipment. Indeed, TPM is an innovative approach to maintenance that seeks to maximize equipment effectiveness. It strives to maintain the equipment in optimum condition in order to avoid speed losses, unexpected breakdown and quality defects. (Ahuja and Khamba, 2008 a, b). TPM contributes to maintain equipment at its highest availability and productivity level. TPM practices are considered as an infrastructure practices essential for any manufacturing system (JIT, TQM, agile manufacturing, etc.)

7. Conclusion, limitations and future research

7.1 Conclusion

This research provides empirical justification for a framework that describes the relationship between TPM, TQM, JIT and agile manufacturing. It examines four research questions: (1, 2) Can successful TPM implementation support JIT development and TQM development? (3) Can successful TQM implementation support JIT development? (4) Do organizations with successful JIT implementation have a high level of agile manufacturing?

This paper provides empirical evidence to support conceptual and prescriptive statements in the literature concerning the agile manufacturing approach. The current research provides empirical evidence that agile manufacturing is directly related to JIT and indirectly related to TPM and TQM. It also provides empirical evidence that lean manufacturing practices (TPM, TQM and JIT) are directly interrelated.

The results also indicate that successful implementation of TPM can support JIT and TQM, successful implementation of TQM can support JIT and successful implementation of JIT can lead to enhance agile manufacturing.

This research also provides empirical evidence to support the mediating role played by JIT in the explanation of the relationship between TPM, TQM and agile manufacturing. The present study demonstrates the efficacy of lean manufacturing practices (TPM, TQM and JIT) in enhancing agile manufacturing. The results motivate managers to implement lean manufacturing practices. The findings of this research, thus, point to the importance of lean manufacturing practices to the organization.

This research is considered as newness in the field of management and manufacturing practices due to the insufficient theoretical studies that develop the relationship between lean manufacturing practices (TPM, TQM and JIT). It clarifies the causal relationship between lean manufacturing practices and their direct and indirect impact on agile manufacturing.

The proposal model would be a helpful support for future studies that focus on effective integration of TPM, TQM and JIT in manufacturing firms.

From a manager's point of view, the current study has important implications for practitioners. This research enriches managers' understanding of the role of TPM, TQM and JIT practices in supporting each other and in creating an appropriate environment to support agile manufacturing system. It also shows practitioners the importance of making TPM, TQM and JIT coexist successfully. Accordingly, it is pertinent to suggest for practitioners who seek to enhance their agility to begin first by implementing TPM practices because, as mentioned previously, they are considered as an infrastructure practices which are essential for any manufacturing system (e.g., TQM and JIT). Then they should implement TQM practices since it is the most adequate system which may ensure the required quality by JIT strategy. As stated earlier, TQM is considered as "an umbrella" for a variety of methods and production tool. Hence, to ensure a successful implementation of TQM, it is necessary to implement TPM practices, and to ensure a successful implementation of JIT, it is essential to implement TPM and TQM systems. It is thus relevant to recommend for managers an effective implementation and support of TPM and TQM in order to create a fertile environment to implement and support JIT strategy. Finally, practitioners should implement JIT in order to ensure a successful implementation and a high level of agile manufacturing. Indeed, JIT is considered as the most adequate system which may ensure the required rapidity and flexibility for an optimal level of organizational agility. Thus, to make TPM, TQM and JIT practices coexist successfully, they should not be treated separately as their combination yields synergies that lead to further agility improvements.

The findings of the present research have imperative multilevel repercussions for firms.

A Commercial impact is explained by the fact that lean manufacturing practices (TPM,TQM and JIT) and agile manufacturing practices provide their implementers with a strong and defensible position over their competitors. Added to that, the aforementioned practices help generate an atmosphere of creativity and innovation and build a confident and solid relationship with suppliers and mainly with customers by meeting rapidly and efficiently their changing *requirement* and increasing the customer satisfaction and loyalty.

An economic impact is explained by a capture of new investment and shareholders, a growth of capital which creates dynamism, and an evolution of the economic market.

This research may also provide teaching implications. It may be useful for teachers, students and researchers seeking to understand the notion of TPM, TQM and JIT (definition and utility) and the relationship that may exist between these practices on one hand, and the notion of agility and its main levers on the other. Findings reveal that there is a certain complementarity between these practices which makes it possible to support and improve organizational agility.

Agile manufacturing system may also play a part in the development of agility culture. Firms are pushed to actualize their organizational culture strategy to yield an environment of responsiveness, flexibility, adaptability, speed, creativity, innovation and employee empowerment and training.

7.2 Limitations and future research

The present study links JIT practices to agile manufacturing and TPM practices to TQM and JIT. It is widely recognized that lean manufacturing practices (JIT, TPM, and TQM) work "synergistically" to improve organizational performance and agile manufacturing. Our research is limited to studying the impact of TQM on JIT and the effect of TPM on TQM and JIT. But literature review reveals that these practices are linked in various ways. Future research aims to study the reverse impact (the effect of TQM and JIT on TPM and the impact of JIT on TQM). Our research is also limited to studying the direct impact of JIT on agile manufacturing and the indirect impact of TPM and TQM on agile manufacturing through JIT. Future research could verify the direct effect of TPM and TQM on agile manufacturing, and to identify the practices that must be relied upon to ensure a high level of agile manufacturing.

In addition, it is widely recognized that Lean manufacturing practices and agile manufacturing contribute to improve business performance. Therefore, studying the direct and indirect effect of lean manufacturing practices and agile manufacturing on organizational performance is recommended in future research.

ORCID iDs

Meriem Khalfallah http://orcid.org/0000-0002-0236-8242

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Appendix 1
Measurement scales

TPM (basic techniques) (Cua *et al.*, 2001)

A. Autonomous and planned maintenance

(1) We dedicate a portion of every day solely to maintenance
(2) We emphasize good maintenance as a strategy for achieving quality and schedule compliance
(3) We have a separate shift, or part of a shift, reserved each day for maintenance activities
(4) Our maintenance department focuses on assisting machine operators perform their own preventive maintenance

B. Technology emphasis

(1) Our plant stays on the leading edge of new technology in our industry
(2) We are constantly thinking of the next generation of technology
(3) We are a leader in the effective use of new process technology
(4) We search for continuing learning and improvement after installation of the equipment

C. Proprietary equipment development

(1) We actively develop proprietary equipment
(2) We rely on vendors for most of our equipment
(3) We have equipment which is protected by the firm's patents
(4) Proprietary equipment helps us gain a competitive advantage

TQM (Choi and Eboch, 1998).

A. Process quality

(1) Worker involvement in machine maintenance
(2) Problem-solving by workers
(3) Continuous improvement
(4) Reactive maintenance by mechanics
(5) Problem solving primarily by technical people
(6) Quality data just to show to customers

B. Human resources

(1) Reward for quality
(2) New skill acquisition
(3) Rewards based on seniority
(4) Improvement suggestions

(5) Timely feedback on suggestions
(6) Profit sharing program
(7) Team-based rewards
(8) Performance data shared with workers
(9) Financial data shared with workers

C. Strategic quality planning

(1) Quality as top priority
(2) Top management commitment
(3) Long-term focus
(4) Production layout according to strategic goals
(5) Organization support for quality
(6) Understanding of mission and vision
(7) Objectives for quality performance
(8) Intermediate goals

D. Information and analysis

(1) Workers' use of statistical process control
(2) SPC data used for machine maintenance
(3) Tolerance specifications driving the production
(4) Easy access to company database
(5) Factual decision making
(6) Customer input on quality improvements
(7) Tracking and analyzing customer satisfaction
(8) Target-based quality

JIT-production (Internal JIT) (Furlan, 2011) (Danese *et al.*, 2012)

(1) We usually complete our daily schedule as planned.
(2) The layout of our shop floor facilitates low inventories and fast throughput.
(3) We use a Kanban pull system for production control.
(4) We have low setup times of equipment in our plant.
(5) We emphasize small lot sizes, to increase manufacturing flexibility.

Agile manufacturing (AM) **(**Inman *et al.*, 2011)

(1) This organization has the capabilities necessary to sense, perceive and anticipate market changes.
(2) The production processes of this organization are flexible in terms of product models and configurations.
(3) This organization reacts immediately to incorporate changes into its manufacturing processes and systems.

(4) This organization has the appropriate technology and techno- logical capabilities to quickly respond to changes in customer demand

(5) This organization's strategic vision emphasizes the need for flexibility and agility to respond to market changes.

(6) This organization has formed co-operative relationships with customers and suppliers.

(7) This organization's managers have the knowledge and skills necessary to manage change.

(8) This organization has the capabilities to meet and exceed the levels of product quality demanded by its customers.

(9) This organization has the capabilities to deliver products to customers in a timely manner and to quickly respond to changes in deliver requirements.

(10) This organization can quickly get new products to market.

Appendix 2

	TQMpq	TQMhr	TQMsqp	TQMia	JITPR	AM	TPMapm	TPMte	TPMped
TQMpq	*0.787*								
TQMhr	0.765	*0.806*							
TQMsqp	0.683	0.758	*0.877*						
TQMia	0.450	0.592	0.574	*0.962*					
JITPR	0.319	0.374	0.376	0.355	*0.845*				
AM	0.624	0.776	0.697	0.589	0.452	*0.796*			
TPMapm	0.418	0.477	0.534	0.222	0.342	0.529	*0.831*		
TPMte	0.536	0.602	0.611	0.336	0.365	0.738	0.635	*0.898*	
TPMped	0.441	0.452	0.431	0.297	0.389	0.555	0.486	0.635	*0.902*

Table A1.
Discriminant validity

Corresponding author
Meriem Khalfallah can be contacted at: meriemkhlf@gmail.com