Australian Journal of Basic and Applied Sciences, 5(12): 1886-1896, 2011
ISSN 1991-8178

An Investigation Into The Relationship Between The Implementation of Lean Manufacturing and Energy Efficiency in Industrial Organizations

[1]Magdy A. Khalaf, [2]Ashraf A. Labib and [3]Aziz E. ElSayed

[1,2,3]Arab Academy for Science, Technology and Maritime Transport P.O.B. 1029, Alexandria, Egypt.

Abstract: There is a general acceptance in literature that implementing lean manufacturing is concerning the effective utilization of available resources. Thus, it is argued that lean implementation may enhance, among others, energy efficiency. In accordance, Khalaf, *et al*., (2010) developed a conceptual model to illustrate how lean manufacturing implementation realizes improvements in energy efficiency through enhancing both labor efficiency and capacity utilization. Based on this conceptual model, a survey is performed with the aim to build mathematical models to validate these conceptually proposed relationships. The developed mathematical models revealed that implementing both the HRM and TQM bundles of lean practices have significant effects on improving labor efficiency and capacity utilization, respectively. Further, the analysis supported the argument that higher labor efficiency as well as higher capacity utilization leads to higher energy efficiency. These results empirically validates that lean manufacturing implementation significantly influence energy efficiency.

Key words: Lean manufacturing, Energy efficiency, Labor efficiency, Capacity utilization, Total quality management (TQM), Just in time (JIT), Total productive maintenance (TPM), Human resources management (HRM).

INTRODUCTION

It is clear that improving energy efficiency becomes a crucial objective for organizations that seek to sustain in highly competitive environment (Mizuta, 2003; Al-Ghanim, 2003; Nagesha, 2008). However, several studies (Rohdin and Thollander, 2006; Kablan, 2003; Nagesha and Balachandra, 2006) highlighted the existence of many barriers that inhibit firms to successfully implementing projects to enhance their energy efficiency. The most critical barrier cited in literature is the financial limitations which prevent many of the small enterprises from achieving energy efficiency by means of up-grading technology (Bala-Subrahmanya, 2006B).

Moreover, Waldemarsson, *et al*. (2010) noted that energy issues are seldom a top priority, even in energy intensive organizations. This can be explained by the severe competitive market which forces companies to spend most of their resources, efforts and time in improving productivity and quality of their products (Rawabdeh, 2005). Consequently, companies give relatively little attention to energy efficiency improvements (Rohdin and Thollander, 2006; Wang, *et al*., 2008).

Nevertheless, it is claimed that energy efficiency improvement is strongly associated with productivity and quality improvements (Boyd and Pang, 2000). So, it is argued that organizations could attain considerable amount of energy efficiency improvement in their pace to improve their manufacturing performance. In this context, lean manufacturing is considered one of the management initiative that focuses on intensifying the effective utilization of resources (including; materials, human, capital, time, physical plant equipment, information and energy) (Papadopoulou and Özbayrak, 2005). Thus, it is generally accepted that implementing lean manufacturing may enhance, among others, energy efficiency. In specific, Khalaf, *et al*. (2010) developed a conceptual model (Figure 1) to illustrate how lean manufacturing implementation realizes improvements in energy efficiency.

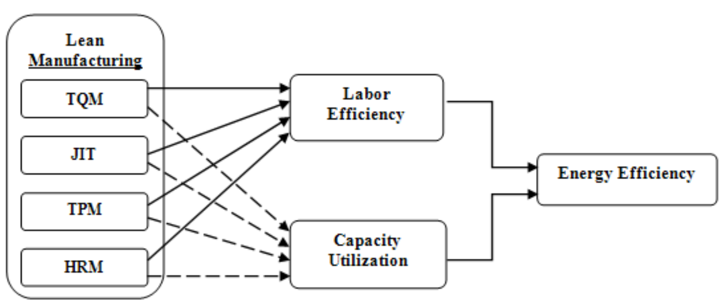

Fig. 1: The conceptual model linking lean manufacturing to energy efficiency.
Source: Khalaf, *et al*., 2010.

Corresponding Author: Arab Academy for Science, Technology and Maritime Transport P.O.B. 1029, Alexandria, Egypt.
Fax: +2-03-5628261; E-mail: m_khalaf@aast.edu.

This conceptual model argues that implementing the four bundles of lean practices; Total Quality Management (TQM), Just In Time (JIT), Total Productive Maintenance (TPM) and Human Resources Management (HRM), leads to improvements in both labor efficiency and capacity utilization which, in turn, contribute in enhancing energy efficiency (Khalaf, *et al*., 2010). Although the proposed relationships of this model is theoretically supported in different researches, further empirical investigation is required to investigate the extent to which lean manufacturing implementation contribute in enhancing energy efficiency through improving labor efficiency and capacity utilization. Thus, the main objective of the current research is to develop mathematical models for linking lean manufacturing to energy efficiency. Consequently, the conceptual relationships between the identified constructs which are; lean manufacturing, labor efficiency, capacity utilization and energy efficiency, should be translated at the empirical level into the research hypotheses.

Literature Review and Research Hypotheses:

Previous studies declared that lean manufacturing enables firms to effectively utilize its human and technological resources (Bhasin and Burcher, 2006; Shah and Ward, 2007). Regarding the human resources, different researches (Antony, *et al*., 2002; Sim and Rogers, 2009) alleged that the effective implementation of TQM practices affects labor efficiency as it results in employee involvement and creates a better communication among workers. Besides, Chapman and Al-Khawaldeh (2002) proved that adopting TQM concepts leads to inspiring employees to succeed and grow and, in turn, improve their performance and efficiency.

Moreover, the effect of JIT practices on labor efficiency was also proved. Salaheldin (2005) concluded that JIT implementations have had a very significant positive impact on workers as it facilitated improvements in the workers' ability to perform their jobs and increased their participation.

TPM activities result in substantial increase in labor productivity through reducing production stoppages and downtimes (Kwon and Lee, 2004), increasing technical skills of production personnel, conducting analysis for the maintenance improvement initiatives and sharing information among different functional areas (Ahuja and Khamba, 2008C; McKone, *et al*., 2001).

It is clear that HRM practices affect labor efficiency in different ways. Zhang, *et al*. (2000) alleged that participation of employees in continuous improvement enables them to improve their personal capabilities, increase their self-respect, commit themselves to the success of their organizations, and change certain personality traits. Delegating work among teams increases workers' sense of discretion, satisfaction, and job security (Olivella, *et al*., 2008). Training facilitates accomplishing a variety of tasks by each employee while compensation system encourages them to overcome resistance to increase the number of tasks they perform (Sánchez and Pérez, 2001). The above discussion leads to formulate the first research hypothesis as follows:

H1: Implementing Lean Manufacturing Practices Improves Labor Efficiency:

On the other hand, several researches declared the influence of adopting lean practices on capacity utilization. Hines and Rich (1997) identified that applying TQM practices, such as Autonomation and autonomous defect control, prevent inappropriate processing of machines which, in turn, improves the utilization of production capacity. In addition, the effect of JIT practices on capacity utilization can be realized in two researches. Hüttmeir, *et al*. (2009) affirmed that the objective of production leveling is to avoid peaks and valleys in the production schedule to permit higher capacity utilization. Lee-Mortimer (2006) also highlighted that reducing set-up time succeed to deliver increased available capacity.

Besides, Eti, *et al*. (2004) affirmed that TPM activities should improve the plant's resources utilization. This can be realized by improving equipment availability and utilization (Ahuja and Khamba, 2008A; Chan, *et al*., 2005) and by discover the hidden but unused or underutilized resources including machine-hours (Ahuja and Khamba, 2008B). Finally, Chen, *et al*. (2003) alleged that investment in human resources can further result in better hardware utilization since HRM is considered an integral function supporting all the improvements of resources management and business functions. In accordance with these studies, the second hypothesis of this research is formulated as follows:

H2: Implementing Lean Manufacturing Practices Improves Capacity Utilization:

It was clearly identified in literature that both labor efficiency and capacity utilization factors, which represent the utilization of production resources in the manufacturing processes, have significant positive influence in enhancing energy efficiency (Bala-Subrahmanya, 2006B; Boyd and Pang, 2000; Al-Ghandoor, *et al*., 2008; Nagesha, 2008).

Rohdin and Thollander (2006) highlighted the need for people with real ambition as a key driving force that have an effect on the implementation rate of energy efficiency measures. In the same vein, different researches (Bala-Subrahmanya, 2006A,B and Nagesha, 2008) proved the positive relationship between energy efficiency and labor productivity, as a measure of labor efficiency. Thus, the third research hypothesis is as follows:

H3: Higher Labor Efficiency Will Lead To Higher Energy Efficiency:

Moreover, Boyd and Pang (2000) and Nagesha (2008) declared that capacity utilization has a strong positive effect on energy efficiency. Likewise, Al-Ghandoor, *et al*., (2008) proved that capacity utilization is one of the most significant factors that affects the changes in electricity consumption. In the same vein, Bala-Subrahmanya (2006A) underscored that a consistent increase in capacity utilization and size as well as value of output would enable an enterprise to realize higher energy efficiency. Consequently, the last research hypothesis is as follows:

H4: Higher Capacity Utilization Will Lead To Higher Energy Efficiency:

Research Methodology:

For testing these hypotheses, a survey is designated to collect data required for building the mathematical models that explain the influence of implementing lean manufacturing practices over the energy efficiency in the industrial sector organizations. Survey research seems best suited to large scale data gathering as it is used to collect information from individuals about the social units to which they belong (Forza, 2002).

The items used to evaluate the implementation of each of the four lean bundles; TQM, JIT, TPM and HRM and the three performance measures namely; labor efficiency (LE), capacity utilization (CU) and energy efficiency (EE) are illustrated in Appendices A-E. Since the aim of this research is to evaluate the effect of implementing lean manufacturing, the survey intends to measure the percentage changes in performance due to lean implementation within industrial sector organizations. Multiple measures of each bundle of practices are averaged to form a scale score for the corresponding bundle to be used in the analysis. The indicators with a decreasing (↓) direction (as shown in Appendices A-D) should be inversed before calculating the bundle scale score.

After collecting the data, multiple linear regression models is constructed to represent the anticipated relationships between energy efficiency and lean manufacturing. Regression analysis is the most widely used statistical technique for investigating and modeling the relationships between variables (Montgomery, *et al*., 2006). Table (1) demonstrates the proposed regression models and the associated variables to be used in testing the research hypotheses.

Table 1: Research hypotheses and the associated regression models.

Hypotheses		Models	Variables	
			Dependent	Independent
H1	Implementing lean manufacturing practices improves labor efficiency.	Model (I)	ΔLE	ΔTQM ΔJIT ΔTPM ΔHRM
H2	Implementing lean manufacturing practices improves capacity utilization.	Model (II)	ΔCU	ΔTQM ΔJIT ΔTPM ΔHRM
H3	Higher labor efficiency will lead to higher energy efficiency.	Model (III)	ΔEE	ΔLE
H4	Higher capacity utilization will lead to higher energy efficiency.	Model (IV)	ΔEE	ΔCU

The survey is performed in two stages. The first stage is guided by the desire to better understand the frequently used measures by different organizations when assessing lean implementation. While the second stage is designated to collect and analyze data required for building the abovementioned mathematical models.

The population of interest for this study is considered to be all manufacturing firms that implement lean manufacturing practices in Egypt. Therefore, a contact list, obtained from Industry Modernization Center (IMC), was selected as the primary source for developing a respondent profile. IMC is a governmental authority that is concerned with supporting and funding the consulting, training, and implementation of improvement programs within Egyptian industrial organizations and, hence, it maintains a large database of manufacturing executives from a diverse set of manufacturing companies.

The obtained list consists of 61 industrial organizations. By contacting each of these organizations, six of them identified that they are still in a preliminary stage of lean implementation and, in turn, they are not suited to share in this study. Accordingly, the remaining 55 industrial organizations are considered as the potential candidates to participate in this research study.

Assessing The Importance of Lean Indicators:

The main target in this stage is to guarantee, as much as possible, the availability of the proposed measures among the surveyed companies. Inconsistent measures among the companies may lead to several missing data that may negatively affect testing the research hypotheses. Accordingly, a questionnaire is designed to assess the degree of importance of each of the proposed lean indicators (shown in Appendices A-D) using a five point

Likert scale ranging from 1 to 5 where a value of 5 indicates fully important and a value of 1 indicates not important.

By sending the questionnaire to the 55 intended respondents, 32 questionnaires are returned which represents a 58.18% response rate. After collecting the data, reliability analysis is conducted to test the goodness and validity of data. The calculated Cronbach's alpha values for the four scales; TQM, JIT, TPM and HRM are ranging from 0.886 (TQM) to 0.933 (JIT) and the overall reliability coefficient is **0.965** which evidenced that the four scales are judged to be reliable.

Furthermore, descriptive analysis is used to identify the respondents' perception towards the importance of the proposed indicators and the aggregated importance of each bundle. Higher scores are indicative of higher degrees of importance. Accordingly, the investigated lean practitioners revealed that all the proposed indicators are highly important as the least important indicator (HRM5) has an average importance equal 2.78 (on a 5 point scale) and the least important bundle of practices (HRM) has an aggregated importance of 3.49. Therefore, it can be concluded that all the proposed indicators (categorized under the four bundles) can be used to assess changes in organizations performance due to implementing different lean manufacturing practices.

Data Collection and Analysis:

After confirming the use of the proposed indicators for assessing changes due to implementing the four lean bundles of practices, the second survey stage is conducted to measure the percentage changes in performance due to lean implementation within industrial organizations with the aim of empirical examination of the research hypotheses.

This survey intended the 32 organizations that participated in the first survey due to their previous willingness of participation in the study and their fully understanding of all the measured indicators. At first, the contact person in the 32 organizations were contacted by phone to provide a brief introduction, objectives and the type of the required data to be gathered for such survey research. Accordingly, a Percentage of Change Measurement Form was sent to the intended respondents through e-mails. The measures in the designed form includes the four lean bundles namely; TQM, JIT, TPM, and HRM and the three performance measures namely; labor efficiency (LE), capacity utilization (CU) and energy efficiency (EE) as explored in Appendices A-E.

The returned survey respondents are 12 out of 32 which represents a 37.5 percent response rate. Consequently, basic descriptive statistics are conducted to ensure that there is only negligible distortion of the questionnaire outputs. The descriptive analysis results (Table 2) illustrated that both the trimmed mean and the median are close to the mean, which indicates that the extreme scores do not have a strong influence on the mean and also there is only a weak distortion of the collected data for all variables.

Table 2: Descriptive analysis.

Variable	Descriptive Statistics				
	Mean		Median	5% Trimmed Mean	Coefficient of Skewness
	Statistic	Std. Error			
ΔEE	26.75	4.37	25.50	26.67	0.136
ΔLE	34.00	4.00	35.50	33.78	0.241
ΔCU	30.50	2.51	30.50	30.89	-1.009
ΔTQM	36.77	4.46	36.63	36.67	0.207
ΔJIT	23.28	3.57	22.53	22.79	0.631
ΔTPM	43.14	8.35	36.81	40.87	1.452
ΔHRM	43.84	4.68	48.10	43.81	-0.085

The validity of the collected data for the four lean bundles scales were identified by calculating Cronbach’s alpha (Table 3). Since the calculated Cronbach's alpha values are higher than 0.6, the research can rely on the collected data for testing the research hypotheses (Antony, *et al*., 2002).

Table 3: Reliability analysis for the four lean bundles scales.

Scale	No. of indicators	Cronbach's alpha
ΔTQM	16	0.614
ΔJIT	16	0.726
ΔTPM	8	0.631
ΔHRM	15	0.606
All indicators	55	0.871

Since regression analysis assumes that variables have normal distributions (Osborne and Waters, 2002), a normality test for each variable was performed. Shapiro-Wilk method is an appropriate technique for sample size smaller than 50 (Myers and Well, 2003). The Shapiro-Wilk normality tests results were non-significant (p-values > 0.05) for all variables (Table 4) which revealed that all the variables are normally distributed which identified that the data is appropriate for conducting regression analysis.

Table 4: Tests of normality.

Variable	Normality Test		
	Statistics	df	p-value
ΔEE	0.950	12	0.637
ΔLE	0.977	12	0.967
ΔCU	0.894	12	0.131
ΔTQM	0.947	12	0.591
ΔJIT	0.948	12	0.613
ΔTPM	0.871	12	0.068
ΔHRM	0.962	12	0.816

Regression Model (I) Analysis:

In this model, the effect of the four lean implementation bundles (TQM, JIT, TPM, and HRM) on labor efficiency (LE) will be investigated to test the first hypothesis (H1). By performing the stepwise regression analysis, the variable ΔHRM is entered into the equation while no further independent variables satisfied the entry criterion (entry p-value < 0.05 and removal p-value > 0.10).

The model summary (Table 5) shows that the model coefficient of determination (adjusted R^2) equals 56.2%, which means that 56.2% of the variation in ΔLE can be explained by differences in ΔHRM. The adjusted R^2 statistic is used to correct the overestimation in the R^2 value when a small sample is involved (Pallant, 2007).

Table 5: Model (I) Summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.776	0.602	0.562	9.16552	2.643

The ANOVA (Table 6), which assesses the overall statistical significance of the model, revealed that model (I) is significant as p-value < 0.05 (Healey, 2009).

Table 6: ANOVA for Model (I).

Model	Sum of Squares	df	Mean Square	F	*p*-value
Regression	1271.933	1	1271.933	15.141	0.003*
Residual	840.067	10	84.007		
Total	2112.000	11			
* Predictors: (Constant), ΔHRM					

The sample regression equation is created from the "Unstandardized Coefficients" in the coefficients table (Table 7) as follows:

$$\Delta LE = 4.947 + 0.663 * \Delta HRM \quad (1)$$

The Standardized Beta Coefficients give a measure of the contribution of the independent variable to the model and the p-values give a rough indication of the impact of the independent variable. Thus, a large standardized beta coefficient (0.776) and the small p-value (0.003 < 0.01) indicate that a unit change in the independent variable (ΔHRM) has a large effect on the dependant variable (ΔLE).

Table 7: Coefficients table for Model (I).

Model	Unstandardized Coefficients		Standardized Coefficients	*t*	*p*-value
	B	Std. Error	Beta		
(Constant)	4.947	7.921		0.625	0.546
ΔHRM	0.663	0.170	0.776	3.891	0.003

With respect to the assumptions regarding residuals distribution, the Durbin-Watson computed value (2.643) is higher than the tabulated upper limit value at 5% significance (1.36) (Freund, *et al.*, 2006). This implies that residuals were actually independent from each other. Furthermore, the result of the Shapiro-Wilk normality test for the model standardized residuals is non-significant (p-value > 0.05) which revealed that the residuals are normally distributed with zero mean and constant standard deviation of approximately 0.953.

Regression Model (II) Analysis:

Model (II) intends to investigate the effect of the four lean implementation bundles on capacity utilization (CU) to test the second hypothesis (H2). By performing the stepwise regression analysis, only the variable ΔTQM is entered into the equation. The model summary (Table 8) declared that the adjusted R^2 equals 40% which means that 40% of the variation in ΔCU can be explained by differences in ΔTQM. Further, the ANOVA results (Table 9) revealed that model (II) is significant as p-value < 0.05.

Table 8: Model (II) Summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.674	0.454	0.400	6.73413	2.632

Table 9: ANOVA for Model (II).

Model	Sum of Squares	df	Mean Square	F	*p*-value
Regression	377.560	1	377.560	8.327	0.016*
Residual	453.440	10	45.344		
Total	831.000	11			
* Predictors: (Constant), ΔTQM					

The sample regression equation is as follows:

$$\Delta CU = 16.544 + 0.380 * \Delta TQM \quad (2)$$

Moreover, from Table (10), the large standardized beta coefficient (0.674) and the small p-value (0.016 < 0.05) indicate that a unit change in the independent variable (ΔTQM) has a large effect on the dependant variable (ΔCU).

Table 10: Coefficients table for Model (II).

Model	Unstandardized Coefficients		Standardized Coefficients	*t*	*p*-value
	B	Std. Error	Beta		
(Constant)	16.544	5.213		3.174	0.010
ΔTQM	0.380	0.132	0.674	2.886	0.016

Since the Durbin-Watson computed value (2.632) is higher than the tabulated value (1.36), the residuals are proved to be independent from each other. The result of the Shapiro-Wilk normality test for the model standardized residuals also revealed that the residuals are normally distributed with zero mean and constant standard deviation of approximately 0.953.

Regression Model (III) Analysis:

In this model, the effect of labor efficiency (LE) on energy efficiency (EE) will be investigated to test the third hypothesis (H3). The model summary (Table 11) revealed that the adjusted R^2 equals 42.1% which means that the differences in ΔLE explain 42.1% of the variation in ΔEE. Further, the ANOVA results (Table 12) revealed that model (III) is significant as p-value < 0.05.

Table 11: Model (III) Summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.688	0.474	0.421	11.51410	1.905

Table 12: ANOVA for Model (III).

Model	Sum of Squares	df	Mean Square	F	*p*-value
Regression	1192.504	1	1192.504	8.995	0.013*
Residual	1325.746	10	132.575		
Total	2518.250	11			
* Predictors: (Constant), ΔLE					

The sample regression equation is as follows:

$$\Delta EE = 1.202 + 0.751 * \Delta LE \quad (3)$$

Table (13) shows a large standardized beta coefficient (0.688) and a small p-value (0.013 < 0.05) which indicate that a unit change in the independent variable (ΔLE) has a large effect on the dependant variable (ΔEE).

Table 13: Coefficients table for Model (III).

Model	Unstandardized Coefficients		Standardized Coefficients	*t*	*p*-value
	B	Std. Error	Beta		
(Constant)	1.202	9.144		0.131	0.898
ΔLE	0.751	0.251	0.688	2.999	0.013

The Durbin-Watson computed value (1.905) is higher than the tabulated value (1.36) which means that residuals are independent from each other. In addition, the residuals are also normally distributed with zero mean and constant standard deviation of approximately 0.953 as the result of the Shapiro-Wilk normality test for the model standardized residuals is non-significant (p-value > 0.05).

Regression Model (IV) Analysis:

In this model, the effect of capacity utilization (CU) on energy efficiency (EE) will be investigated to test the last hypothesis (H4). Since the adjusted R^2 equals 35.0% (Table 14), the differences in ΔCU explain 35.0% of the variation in ΔEE. Further, the ANOVA results (Table 15) revealed that model (IV) is significant as p-value < 0.05.

Table 14: Model (IV) Summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.640	0.409	0.350	12.19633	2.156

Table 15: ANOVA for Model (IV).

Model	Sum of Squares	df	Mean Square	F	*p*-value
Regression	1030.746	1	1030.746	6.929	0.025*
Residual	1487.504	10	148.750		
Total	2518.250	11			
* Predictors: (Constant), ΔCU					

The sample regression equation is as follows:

$$\Delta EE = -7.218 + 1.114 * \Delta CU \quad (4)$$

The large standardized beta coefficient (0.640) and the small p-value (0.025 < 0.05) (shown in Table 16) indicate that a unit change in the independent variable (ΔCU) has a large effect on the dependant variable (ΔEE).

Table 16: Coefficients table for Model (IV).

Model	Unstandardized Coefficients		Standardized Coefficients	*t*	*p*-value
	B	Std. Error	Beta		
(Constant)	-7.218	13.376		-0.540	0.601
ΔCU	1.114	0.423	0.640	2.632	0.025

Since the Durbin-Watson computed value (2.156) is higher than the tabulated value (1.36), the residuals are proved to be independent from each other. The result of the Shapiro-Wilk normality test for the model standardized residuals also revealed that the residuals are normally distributed with zero mean and constant standard deviation of approximately 0.953.

Discussion and Conclusions:

The key objective of this research is to construct regression models that transform the conceptual model proposed in Khalaf, *et al*. (2010) into mathematical form. Accordingly, this research contributes to the existing knowledge by providing an empirical evidence to the effect of implementing lean manufacturing on energy efficiency. In specific, the research results evidence that implementing the human resources management (HRM) bundle of lean practices contributes in enhancing labor efficiency while the total quality management (TQM) bundle of lean practices is proved to have a significant influence over capacity utilization.

Besides, the empirical findings support, on one hand, that improving labor efficiency, as a result of lean manufacturing implementation, significantly contributes in improving energy efficiency. On the other hand, the research also supports the argument that increasing capacity utilization leads to enhancing energy efficiency. Thus, these results confirm the claim that implementing lean manufacturing will lead to improvements in energy efficiency through improving labor efficiency and capacity utilization. Consequently, the conceptual model (Figure 1) is modified as shown in Figure (2).

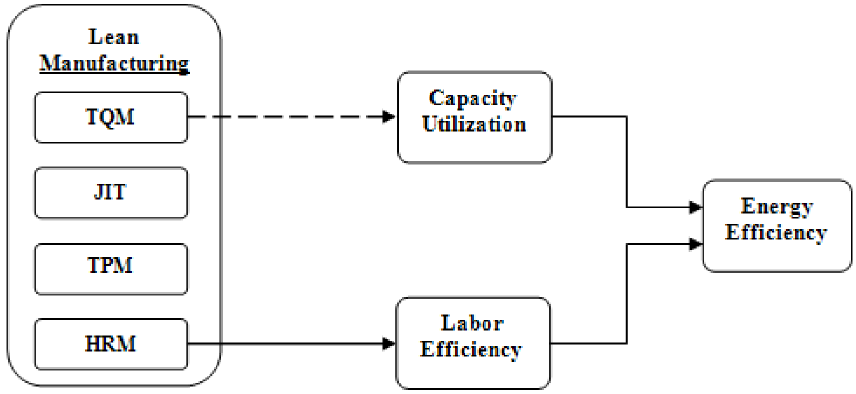

Fig. 2: The developed model linking lean manufacturing to energy efficiency.

REFERENCES

Ahuja, I.P.S. and J.S. Khamba, 2008A. "Strategies and success factors for overcoming challenges in TPM implementation in Indian manufacturing industry", *Journal of Quality in Maintenance Engineering*, 14(2): 123-147.

Ahuja, I.P.S. and J.S. Khamba, 2008B. "Total productive maintenance: literature review and directions", *International Journal of Quality and Reliability Management*, 25(7): 709-756.

Ahuja, I.P.S. and J.S. Khamba, 2008C. "Justification of total productive maintenance initiatives in Indian manufacturing industry for achieving core competitiveness", *Journal of Manufacturing Technology Management*, 19(5) 645-669.

Al-Ghandoor, A., I. Al-Hinti, J.O. Jaber and S.A. Sawalha, 2008. "Electricity consumption and associated GHG emissions of the Jordanian industrial sector: Empirical analysis and future projection", *Energy Policy*, 36: 258-267.

Al-Ghanim, A., 2003. "A statistical approach linking energy management to maintenance and production factors", *Journal of Quality in Maintenance Engineering*, 9(1): 25-37.

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

Bala-Subrahmanya, M.H., 2006A. "Energy intensity and economic performance in small scale bricks and foundry clusters in India: does energy intensity matter?", *Energy Policy*, 34: 489–497.

Bala-Subrahmanya, M.H., 2006B. "Labour productivity, energy intensity and economic performance in small enterprises: A study of brick enterprises cluster in India", *Energy Conversion and Management*, 47: 763-777.

Bhasin, S. and P. Burcher, 2006. "Lean viewed as a philosophy", *Journal of Manufacturing Technology Management*, 17(1): 56-72.

Boyd, G.A. and J.X. Pang, 2000. "Estimating the linkage between energy efficiency and productivity", *Energy Policy*, 28: 289-296.

Chan, F.T.S., H.C.W. Lau, R.W.L. Ip, H.K. Chan and S. Kong, 2005. "Implementation of total productive maintenance: A case study", *International Journal of Production Economics*, 95: 71-94.

Chapman, R. and K. Al-Khawaldeh, 2002. "TQM and labour productivity in Jordanian industrial companies", *The TQM Magazine*, 14(4): 248-262.

Chen, L-H., S-Y. Liaw and T-Z. Lee, 2003. "Using an HRM pattern approach to examine the productivity of manufacturing firms – an empirical study", *International Journal of Manpower*, 24(3): 299-318.

Eti, M.C., S.O.T. Ogaji and S.D. Probert, 2004. "Implementing total productive maintenance in Nigerian manufacturing industries", *Applied Energy*, 79: 385-401.

Forza, C., 2002. "Survey Research in Operations Management: A Process-Based Perspective", *International Journal of Operations & Production Management*, 22(2): 152-194.

Freund, R.J., W.J. Wilson and P. Sa, 2006. "*Regression Analysis: Statistical Modeling of a Response Variable*", Second Edition, Elsevier Inc.

Healey, J.F., 2009. "*Statistics: A Tool for Social Research*", Eighth Edition, Wadsworth Cengage Learning.

Hines, P. and N. Rich, 1997. "The seven value stream mapping tools", *International Journal of Operations and Production Management*, 17(1): 46-64.

Hüttmeir, A., S. de Treville, A. Ackere, L. Monnier and J. Prenninger, 2009. "Trading off between heijunka and just-in-sequence", *International Journal of Production Economics*, 118: 501-507.

Kablan, M.M., 2003. "Energy conservation projects implementation at Jordan's industrial sector: a total quality management approach", *Energy*, 28:1533-1543.

Khalaf, M.A., A.A. Labib and Aziz. E. ElSayed, 2010. "A conceptual model for linking lean manufacturing to energy efficiency", *17th International Annual EurOMA Conference: Managing Operations in Service Economies*, June 6-9, Porto, Portugal.

Kwon, O. and H. Lee, 2004. "Calculation methodology for contributive managerial effect by OEE as a result of TPM activities", *Journal of Quality in Maintenance Engineering*, 10(4): 263-272.

Lee-Mortimer, A., 2006. "A lean route to manufacturing survival", *Assembly Automation*, 26(4): 265-272.

McKone, K.E., R.G. Schroeder and K.O. Cua, 2001. "The impact of total productive maintenance practices on manufacturing performance", *Journal of Operations Management*, 19: 39-58.

Mizuta, Y., 2003. "A case study on energy saving and new energy services in Japan", *Management of Environmental Quality: An International Journal*, 14(2): 214-220.

Montgomery, D.C., E.A. Peck and G.G. Vining, 2006. "*Introduction to Linear Regression Analysis*", Fourth Edition, John Wiley & Sons, Inc.

Myers, J.L. and A.D. Well, 2003. "*Research Design and Statistical Analysis*", Second Edition, Lawrence Erlbaum Associates, Inc.

Nagesha, N. and P. Balachandra, 2006. "Barriers to energy efficiency in small industry clusters: Multi-criteria-based prioritization using the analytic hierarchy process", *Energy*, 31: 1969-1983.

Nagesha, N., 2008. "Role of energy efficiency in sustainable development of small-scale industry clusters: an empirical study", *Energy for Sustainable Development*, 12(3): 34-39.

Olivella, J., L. Cuatrecasas and N. Gavilan, 2008. "Work organisation practices for lean production", *Journal of Manufacturing Technology Management*, 19(7): 798-811.

Osborne, J.W. and E. Waters, 2002. "Four assumptions of multiple regression that researchers should always test", *Practical Assessment, Research and Evaluation*, 8(2). Available from: http://PAREonline.net/getvn.asp?v=8&n=2 [Accessed 15 March 2011].

Pallant, J., 2007. "*SPSS Survival Manual: A Step by Step Guide to Data Analysis using SPSS for Windows*", Third Edition, McGraw-Hill.

Papadopoulou, T.C. and M. Özbayrak, 2005. "Leanness: experiences from the journey to date", *Journal of Manufacturing Technology Management*, 16(7): 784-807.

Rawabdeh, I.A., 2005. "A model for the assessment of waste in job shop environments", *International Journal of Operations and Production Management*, 25(8): 800-822.

Rohdin, P. and P. Thollander, 2006. "Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden", *Energy*, 31: 1836-1844.

Salaheldin, S.I., 2005. "JIT implementation in Egyptian manufacturing firms: some empirical evidence", *International Journal of Operations and Production Management*, 25(4): 354-370.

Sánchez, A.M. and M.P. Pérez, 2001. "Lean indicators and manufacturing strategies", *International Journal of Operations and Production Management*, 21(11): 1433-1451.

Shah, R. and P.T. Ward, 2007. "Defining and developing measures of lean production", *Journal of Operations Management*, 25(4): 785-805.

Sim, K.L. and J.W. Rogers, 2009. "Implementing lean production systems: barriers to change", *Management Research News*, 32(1): 37-49.

Waldemarsson, M., M. Rudberg and H. Lidestam, 2010. "Energy management in process industries: current practices and future challenges", *17th International Annual EurOMA Conference: Managing Operations in Service Economies*, June 6-9, Porto, Portugal.

Wang, G., Y. Wang, and T. Zhao, 2008. "Analysis of interactions among the barriers to energy saving in China", *Energy Policy*, 36(6):1879-1889.

Zhang, Z., A. Waszink and J. Wijngaard, 2000. "An instrument for measuring TQM implementation for Chinese manufacturing companies", *International Journal of Quality and Reliability Management*, 17(7): 730-755.

Appendix A: Measurements of TQM bundle.

Indicator	Definition	Direction*
TQM 1	Value of scrap in relation to sales	↓
TQM 2	Value of rework in relation to sales	↓
TQM 3	Percentage of defective parts adjusted by production line workers	↑
TQM 4	Number of people dedicated primarily to quality control	↓

TQM 5	Size of the adjustment and repair area	↓
TQM 6	Percentage of inspection carried out by autonomous defect control	↑
TQM 7	Percentage of work areas where visible graphs & panels are used (control charts)	↑
TQM 8	Percentage of equipment / processes under SPC	↑
TQM 9	Percentage of parts designed by cross-functional teams	↑
TQM 10	Percentage of common parts in company products	↑
TQM 11	Percentage of parts co-designed with suppliers	↑
TQM 12	Percentage of procedures which are written recorded in the company	↑
TQM 13	The frequency of visits between company's and suppliers' technicians	↑
TQM 14	Number of suggestions made to suppliers	↑
TQM 15	Number of customer complaints	↓
TQM 16	Percentage of improvement projects in which customers are involved	↑
* The desired direction of the indicator, if moving in a lean direction:		
↑	should increase	
↓	should decrease	

Appendix B: Measurements of JIT bundle.

Indicator	Definition	Direction*
JIT 1	Value of WIP in relation to sales	↓
JIT 2	Lead time to customer order	↓
JIT 3	Total product cycle time	↓
JIT 4	Set up times (Amount of time needed for die changes)	↓
JIT 5	Production and delivery lot sizes	↓
JIT 6	The percentage of stages in the material flow that uses pull system	↑
JIT 7	Number of times parts are transported	↓
JIT 8	Total physical distance parts are transported	↓
JIT 9	Materials handling costs	↓
JIT 10	Value of finished goods inventory	↓
JIT 11	Average number of suppliers in the most important parts	↓
JIT 12	Average contract length with the most important suppliers	↑
JIT 13	Value of raw material inventory	↓
JIT 14	On-time delivery (amount of lateness)	↓
JIT 15	Percentage of products delivered JIT between sections in the production line	↑
JIT 16	Percentage of products delivered JIT by the suppliers	↑
* The desired direction of the indicator, if moving in a lean direction:		
↑	should increase	
↓	should decrease	

Appendix C: Measurements of TPM bundle.

Indicator	Definition	Direction*
TPM 1	OEE (Overall Equipment Effectiveness)	↑
TPM 2	Percentage of plant where there are lines on floor distinguishing different spaces.	↑
TPM 3	Percentage of autonomous maintenance over total maintenance	↑
TPM 4	Percentage of preventive maintenance over total maintenance	↑
TPM 5	The ratio of achieved to planned work	↑
TPM 6	MTBF (Mean Time Between Failures)	↑
TPM 7	MTTR (Mean Time To Repair)	↓
TPM 8	Maintenance cost	↓
* The desired direction of the indicator, if moving in a lean direction:		
↑	should increase	
↓	should decrease	

Appendix D: Measurements of HRM bundle.

Indicator	Definition	Direction*
HRM 1	Number of suggestions per employee and year	↑
HRM 2	Percentage of implemented suggestions	↑
HRM 3	Total number of completed Kaizen	↑
HRM 4	Percentage of employees rotating tasks within the company	↑
HRM 5	Average frequency of task rotation	↑
HRM 6	Number of different tasks which employees are trained in	↑
HRM 7	Percentage of employees working in teams	↑

Indicator	Definition	Direction*
HRM 8	Percentage of tasks in product flow performed by the teams	↑
HRM 9	The number of different indirect tasks performed by teams	↑
HRM 10	The ratio of indirect employees in relation to direct employees	↓
HRM 11	Number of job classifications	↓
HRM 12	Amount (in hours) of training given to employees	↑
HRM 13	Number of strategic areas contained in the information given to employees	↑
HRM 14	The frequency with which information is given to employees	↑
HRM 15	Number of informative top management meetings with employees	↑
* The desired direction of the indicator, if moving in a lean direction:		
↑	should increase	
↓	should decrease	

Appendix E: Performance measurements.

Indicator	Definition
LE	Labor Efficiency (Production per Employee)
CU	Capacity Utilization (Actual Production to Ideal Production)
EE	Energy Efficiency (Production per unit of Energy consumed)