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Evaluation and Analysis of Lean-Based Manufacturing Equipment and Technology System for Jordanian Industries

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***Abstract*—**International markets driven forces are changing continuously, therefore companies need to gain a competitive edge in such markets. Improving the company's products, processes and practices is no longer auxiliary. Lean production is a production management philosophy that consolidates work tasks with minimum waste resulting in improved productivity. Lean production practices can be mapped into many production areas. One of these is Manufacturing Equipment and Technology (MET). Many lean production practices can be implemented in MET, namely, specific equipment configurations, total preventive maintenance, visual control, new equipment/ technologies, production process reengineering and shared vision of perfection**.**The purpose of this paper is to investigate the implementation level of these six practices in Jordanian industries. To achieve that a questionnaire survey has been designed according to five-point Likert scale. The questionnaire is validated through pilot study and through experts review. A sample of 350 Jordanian companies were surveyed, the response rate was 83%. The respondents were asked to rate the extent of implementation for each of practices. A relationship conceptual model is developed, hypotheses are proposed, and consequently the essential statistical analyses are then performed. An assessment tool that enables management to monitor the progress and the effectiveness of lean practices implementation is designed and presented. Consequently, the results show that the average implementation level of lean practices in MET is 77%, Jordanian companies are implementing successfully the considered lean production practices, and the presented model has Cronbach's alpha value of 0.87 which is good evidence on model consistency and results validation.

***Keywords*—**Lean Production, SME applications, Visual Control, New equipment/technologies, Specific equipment configurations, Jordan

I. Introduction

TO enhance the competitiveness of Jordanian enterprises, companies embrace a series of proven techniques; one of them is lean production (LP) that consolidates work tasks with minimum waste resulting in greatly reduced wait time, queue time, and other delays. It involves identifying and eliminating non-value adding activities in design, production, supply chain management and customer relations.

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Lean production, as a concept, has two driving forces: to continuously eliminate the source of waste, and to continuously add value. LP is the elimination of anything not absolutely required to deliver a quality product or service, on time, to our customers. Lean production is doing what you do in the least wasteful way possible. That's the heart of LP. The "Soul" of lean production is getting everyone involved in the continuous improvement process so they treat the company, suppliers and customers like they own the place. LP is doing more with less inventory, fewer workers, less space. Lean production as a philosophy is to shorten lead times and reduce costs by eliminating waste and improving employee performance, skills and satisfaction [1]. Non-value adding sources can be structured into; [2] overproduction, waiting, unnecessary transport or conveyance, over processing or incorrect processing, unnecessary movement, defects, and unused employee creativity. Lean Production is a set of tools and methodologies that aims for the continuous elimination of such sources. The goal benefit of that is the productivity improvement [3].

Lean practices and tactics involved when managing Manufacturing Equipment and Technology (MET) system are the focus of this research. Results of this paper are expected to provide advanced insights into the adoption of such lean practices and their effect on managing MET system. A relationship model between MET constitutes will be proposed, a proper data collection method will be followed; consequently a comprehensive statistical analysis using SPSS, AMOS, and LISREL software will be conducted.

II. Lean-Based Manufacturing Equipment and Technology System

Management MET may involve several lean practices such as; specific equipment configurations (group technology, cellular layouts, and continuous flow), total preventive maintenance, visual control, new equipment/technologies, production process reengineering and shared vision of perfection. Table I summarizes such practices; subsequence sections provide a brief explanation about each.

A. Specific equipment configurations

Specific equipment configurations are a supporting discipline, according to lean principles such discipline could be considered as a source of waste. However a total lack of specific equipment configurations would lead to a chaotic situation without any progress at all in most projects, the difficulty lies in identifying just enough specific equipment configurations to be effective without waste [4].

TABLE I
LEAN PRACTICES IN MET IMPACT AREA

Impact Area	Lean Production Practice
Manufacturing Equipment and Technology MET	1. Equipment configurations 2. Total preventive maintenance 3. Visual control 4. New equipment/technologies 5. Processes reengineering 6. Shared vision of perfection

Group Technology (GT) is a processing philosophy based on the principle that similar products should be processed similarly. GT is a technique for identifying and bringing together related or similar components in a production process in order to take advantage of their similarities to gain the inherent economies of flow line production. However, the scope and scale of implementation will vary with the variety of components being made, the volumes of production, the stability of demand, and most importantly, the production processes required to make them. Cellular layout and continuous production flow can be followed to eliminate waste when considering specific equipment configuration.

B. Total preventive maintenance

Preventive maintenance (PM) is defined as a periodic inspection, and preventive repairs designed to reduce the probability of machine breakdown [5]. The primary reasons for preventive maintenance are to reduce unexpected downtime and repair costs caused by machine breakdown. When maintenance is delayed, one risks losing the true value of the capital, premature equipment failure, and product damage and production delays. Essential care is a compilation of processes that will prevent failures from occurring. For example lubrication, alignment, balancing, cleaning, and operating procedures, adjustments and installation procedures. PM is essential care that prevents failures and fixed time maintenance together. PM reduces the amount of reactive maintenance to a level that allows other practices in the maintenance process to be cost effective [6]. In LP organizations, the maintenance function assumes greater responsibility and has greater visibility. The LP organizations rely much more heavily on the operator for many of the maintenance tasks, especially simple PM [7]. Since operators are the closest to the machines, they are included in maintenance and monitoring activities in order to prevent and provide warning of malfunctions [8]. LP is essential to prevent maintenance needs and to perform the remaining maintenance more effectively. If the previous concepts are implemented, then the production reliability will increase and thus production costs, including maintenance costs and costs for storage decreases.

C. Visual control

Visual control (VC) is any communication mean used in the work environment that tells at a glance how work should be done and whether it is deviating from the standard. It helps employees to see immediately how they are doing. VC shows where items belong, how items belong there, what standard procedure is, the status of work in process, and other production data. In the broadest sense, visual control refers to the design of Just-In-Time (JIT) information of all types to ensure fast and proper execution of operations and processes [2]. It is a process to help increase efficiency and effectiveness by making things visible using visual signals. When things are visible, they are kept in conscious mind that helps everyone to have a common viewpoint of what is being displayed [9]. Implementing VC would help companies to exposing abnormalities, problems, deviations, waste, unevenness, and unreasonability to people, thus corrective actions can be taken immediately, therefore waste can be reduced.

D. New equipment/ technologies

As corporations expand into new markets, their success is in part determined by the ability to transfer competitive technologies to local subsidiaries. A good technology transfer can enable a company to improve productivity. Technology is embodied in every value activity of a company and is involved in achieving linkages between activities. By improving efficiency of these activities, technology helps to reduce waste [10]. Technology is knowledge of systematization, and it is about design, production method or management system involved hardware or software. It focuses on the know-how towards a specific technique and method to solve a problem. Technology has been evolved by science research and it is a critical element for economic development of industry [10]. With the rapid advancement of technology, product life cycle is shortening continuously. In order to compete against other companies in competitive global markets, a company has to keep developing new technology to differentiate itself from others. The acquisition of new core technology equipment is especially important for manufacturing advanced products, and the technology know-how of the equipment must be transferred completely from equipment supplier to engineers and operators of the firm to effectively utilize the equipment [11].

E. Production process reengineering

Production process reengineering also known as business process reengineering (BPR) is defined as a radical redesign of processes in order to gain significant improvements in cost, quality, and service, thereafter to reduce waste [12]. Companies have been reengineering various business functions for years, ranging from customer relationship management to order fulfillment, and from assembly lines to logistics. A business process [13] is a series of steps designed to produce a product or a service. It includes all the activities that deliver particular results for a given customer. Business process reengineering is one approach for redesigning the way work is done to better support the organization's mission and reduce waste.

F. Shared vision of perfection

A basic LP principle is to seek perfection; it would suggest there is no end to an organization's lean journey. Leadership strategies that target perfection, focus on means, and sustain commitment maximally position individuals and businesses to become excellent [14]. Perfection begins in small ways by doing excellent work. Perfection consists not in doing amazing things, but in doing ordinary things extremely well [15]. LP principles begin with a systemic evaluation of waste throughout the entire product value chain, actively engage employees on an on-going basis, depend on and reflect close coordination with customers and suppliers, and develop, track, and publicly display performance metrics. Importantly, these principles are also embedded in a continual improvement system that reflects a commitment to "pursue perfection" and the belief that improvements and change is never complete [16].

III. Problem Definition Objectives And Methodology

Organizations of all sizes are trying to stay productive for a long-term period. Most companies have a major opportunity to reduce source of waste through the application of LP principles. LP implies many tools and techniques that allow solving various problems thought the elimination of source of wastes in various production areas such as managing MET systems, Production and inventory control, Shop floor management product design and development etc.

Implementation of LP practices in such impact areas of production provides a potential solution to improve the competitiveness of industries; therefore a development of an assessment tool for the implementation of lean principles can effectively guide the implementation. A need for such assessment tool arises to improve company's efficiency. The implementation of the right lean practice at the right time on the right impact area of production relies on extensive knowledge and experiences.

The main goal of this paper is to investigate the implementation of the six lean practices listed in table 1 that enable Jordanian industries managing MET system successfully according to LP principles, then to develop an assessment tool for measuring the implementation level of every considered lean practice, that provides an effective way to guide and evaluate the implementation process. The effort exerted in this paper aims also to empirically evaluate the level of awareness LP principles.

In order to achieve the aforementioned objectives, questionnaire is selected as a data collection method, since it is feasible and available way to be used in this type of research. A sample of 350 Jordanian companies was surveyed. The respondents were asked to rate the extent of implementation for each of practices. A relationship conceptual model is developed, hypotheses are proposed, and consequently the essential statistical analyses are then performed.

IV. Data Collection and Model Analysis

Questionnaire packets were personally distributed to a total of 350 companies. A total of 290 companies responded; which generates a response rate of a bout 83%, data were collected through production managers, quality engineers, consultants, and owners. A five-point Likert scale (Poor, Fair, Good, Very good, and Excellent) was used. The questionnaire was designed to direct respondents to follow-on items, only if the overall practice was used within the organization. The structure chosen for the survey items not only minimized the amount of time to complete the survey, but also provided the respondent with additional details on a particular practice through the follow-on items. Because the follow-on items referenced more specific aspects of the LP practice in question, this reduced the likelihood that the respondent would misunderstand the overall practice. To evaluate the level of LP awareness and lean practice implementation at a given company, a set of commonly applied LP elements were identified from previous research [17, 18, and 2] and experienced. The questionnaire was reviewed by some experts who are working in consultation companies; feedback was also obtained from other specialists. In addition to that, a pre-test pilot study was conducted. A random sample of 25 companies was selected to test the questionnaire for clarity, comprehensiveness, and acceptability [19]. An electronic mail consisted of a personalized cover letter and a survey questionnaire was sent to each of the 25 companies. The received responses were carefully analyzed.

Responses of participants were collected, coded, and entered into a Microsoft Excel spreadsheet. Then detailed statistical analysis has been carried out. Frequency distributions, contingency tables, and descriptive statistics were used to summarize high-level analysis of responses [19].

V. The Proposed Lean -BASED MET Relationship Model

The developed relationship conceptual model is shown in Figure 1; the figure illustrates the hypotheses between the different lean practices of the MET model. The related proposed hypotheses proposed are explained in Table II

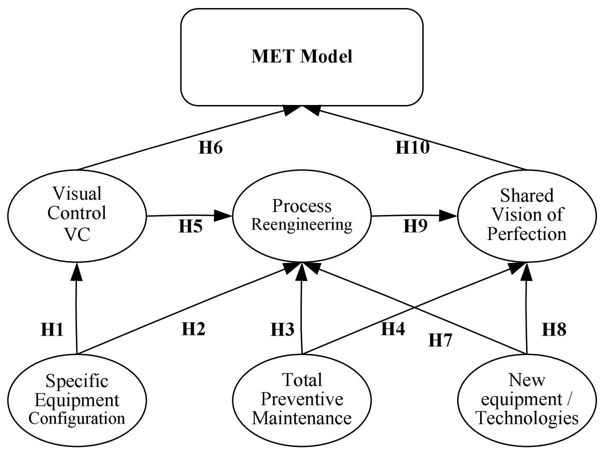

Fig. 1 Relationship conceptual MET model

TABLE II
SUMMARY OF PROPOSED HYPOTHESES FOR MET

	Hypothesis	Ref.
H1	Specific equipment configurations are positively related to visual control.	[17, 19]
H2	Specific equipment configurations have a significant, positive effect on process reengineering.	[20, 21, 22, 23]
H3	Total preventive maintenance has a significant, positive effect on process reengineering.	[24]
H4	Total preventive maintenance has a significant, positive effect on shared vision of perfection.	[6]
H5	Visual control has a significant, positive effect on production process reengineering.	[25]
H6	Visual control has a significant, positive effect on MET	
H7	New equipment/ technologies are positively related to process reengineering.	[26, 27, 11]
H8	New equipment/ technologies have a significant, positive effect on shared vision of perfection.	[28]
H9	Process reengineering has a significant, positive effect on shared vision of perfection.	[29, 30]
H10	Shared vision of perfection has a significant, positive effect on MET.	[14]

VI. THE DEVELOPED ASSESSMENT TOOL

The developed assessment tool reviews the level of implementing lean practice, the tool is used in conjunction corporate goals for MET and it's lean practices to point out areas of opportunity for "Breakthrough Improvement", to monitor progress and effectiveness of the process improvement effort, and to provide a sense of where the company is today on its lean journey. The assessment tool is based on an Excel Spreadsheet; navigates through the tabs shown as Figure 2. Begin by clicking "Introduction" Tab, followed by the "Specific" Tab, entering a score of 1 to 5; continue for the six lean practices. Once the 6 scores are entered, a composite score is automatically calculated, then a Spider Graph for quick review as shown in figure 3 is automatically generated.

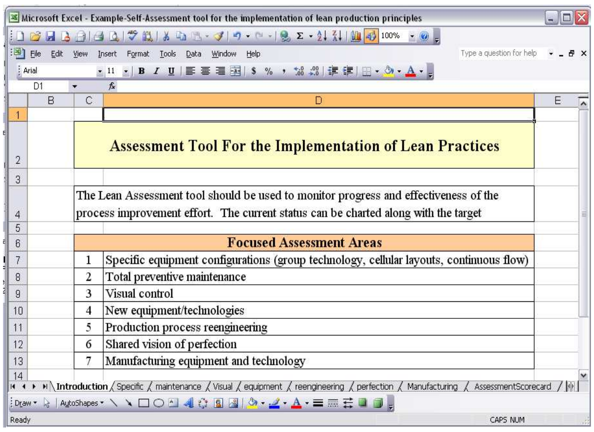

Fig. 2 The developed assessment tool

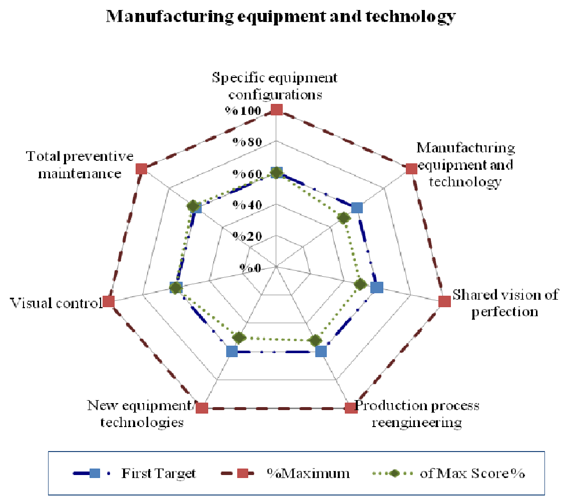

Fig. 3 Spider graph of the developed assessment tool

VII. INTERPRETATION OF RESULTS

For each lean practice, practice score average for all received responses is calculated, consequently implementation level of the practice is evaluated, results are interpreted as explained as in Table III.

TABLE III
RESULTS INTERPRETATION KEY

I% ≤ 20%	**20% < I% ≤ 40%**	**40% < I% ≤ 60%**	**60% < I% ≤ 80%**	**80% < I% ≤ 1000%**
Poor	Fair	Good	Very Good	Excellent

For example; considerer the first leans practice: "specific equipment configurations". Questions score average and practice score averages of responses are represented in Table IV.

TABLE IV
SPECIFIC EQUIPMENT CONFIGURATIONS QUESTIONS AND THEIR AVERAGES

lean practice: Specific equipment configurations	
Question	**Question Score average**
The equipment follows a documented procedure to control changes to configuration items/units.	4.06
Changes in the definition of the product and its specific components are tracked and reported.	3.51
Periodic audits are performed to verify that equipment baselines conform to the documentation that defines them.	4.10
Products are classified into groups with similar process requirements.	3.93
Awareness of the variety of specific equipment configurations that can be utilized to improve the production process.	4.00
Work cells have been developed and implemented to support specific product families and equipment configurations.	3.76
Practice score average	**3.89**
Implementation level of lean practice I%	**78 %**

VIII. Hypotheses and Statistical Analysis

For more detailed statistical analysis Collected data was entered into spread sheet and then it was uploaded to the Statistical Package for Social Sciences SPSS software version 19. The model was checked, validated and tested by Amos 16 software; results are presented in Figure 4. The analysis of developed model includes the following statistical analysis tests.

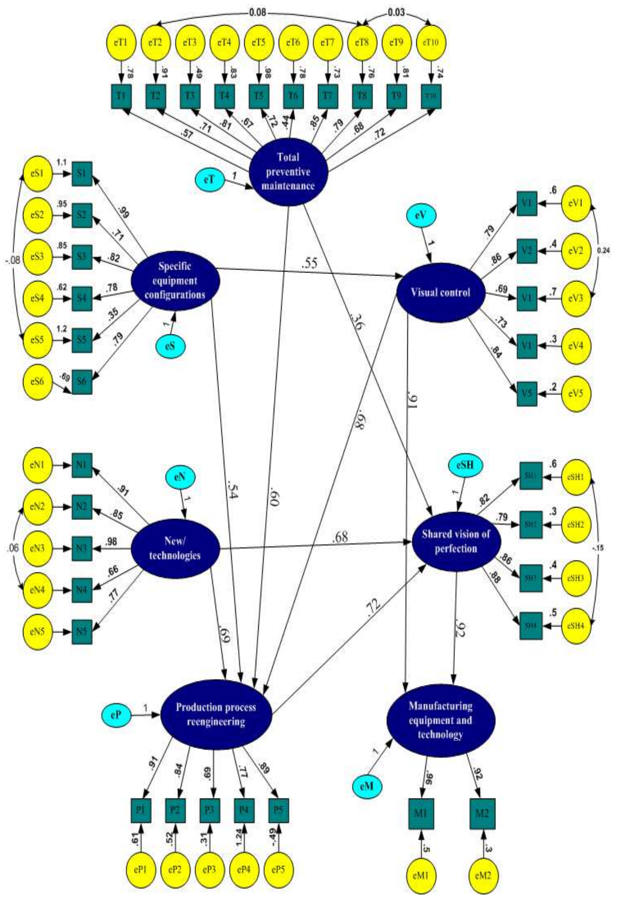

Fig. 4 Model Analysis Using Amos 16 Software tool

A. Multicollinearity Test

Multicollinearity test was conducted between the questions of each lean practice in the MET model; correlation matrix for every lean practice is investigated, as an example of correlation matrix between components of specific equipment configurations latent is sown in Table V Results indicate that all lean practices have a positive correlation with entire MET.

B. Reliability Test

Cronbach's alpha coefficient is used to measure internal consistency and model reliability. Table VI represented Cronbach's alpha for MET model constitutes. A value of 0.6 or less for Cronbach's alpha generally indicates unsatisfactory consistency reliability [31]. Results show that all model constitutes have a value of Cronbach's alpha of greater than 0.7, the overall model has a high Cronbach's alpha value of 0.87.

C. Model fitness

A classic goodness-of-fit measure to determine overall model fit is $\chi2$. A large $\chi2$ and rejection of the null hypothesis means that model estimates do not sufficiently produce sample covariance; the model does not fit the data well. By contrast, a small $\chi2$ and failure to reject the null hypothesis is a sign of a good model fit. Another commonly reported statistic is the Root Mean Square Error of Approximation (RMSEA), incorporates a penalty function for poor model parsimony and thus becomes sensitive to the number of parameters estimated and relatively insensitive to sample size. The Amos user's guide suggests that a value of the RMSEA of about 0.05 or less would indicate a close fit of the model in relation to the Degrees of Freedom (DF).

Another test used to compare models with respect to model parsimony is the Comparative Fit Index (CFI) that evaluates the fit of a user-specified solution in relation to a more restricted, nested baseline model, the covariance among all input indicators are fixed to zero or no relationship among variables is posited.

In general, if the ratio between the chi square goodness of fit measure and degrees of freedom is less than 5, the model is accepted [32]. In this model, the ratio is 3.12 less than 5.0, which is accepted according to the recommended value.

Generally, the fit of the model using chi-square is not always as straight forward as assessment of the fit of the model, because chi-square value is not independent of sample size. Minimization was achieved for the developed model with a degrees of freedom of (681) and probability level of ($p = 0.00$) which is less than $p < 0.01$ [28], as in Table VII. The results are within the acceptable ranges of the recommended values. Convergent validity was assessed by reviewing the t-tests for each hypothesis. If all the hypotheses for the relations were greater than twice their standard errors, the parameter estimates demonstrated convergent validity. The results showed that all t-tests were effectively measuring the same construct.

TABLE V
CRONBACH'S FOR EACH LATENT

Lean production practice (latent)	Cronbach's alpha
Specific equipment configurations	0.78
Total preventive maintenance	0.73
Visual control	0.80
New equipment/ technologies	0.79
Production process reengineering	0.85
Shared vision of perfection	0.83
The overall MET model	**0.87**

TABLE VI
SPECIFIC EQUIPMENT CONFIGURATIONS QUESTIONS AND THEIR AVERAGES

Question	S1	S2	S3	S4	S5	S6
S1	1.00	0.33	0.24	0.12	0.05	0.17
S2	0.33	1.00	0.04	0.25	0.06	0.04
S3	0.24	0.04	1.00	0.39	0.11	0.13
S4	0.12	0.25	0.39	1.00	0.02	0.11
S5	0.05	0.06	0.11	0.02	1.00	0.26
S6	0.17	0.04	0.13	0.11	0.26	1.00

TABLE VII
RESULTS FOR THE HYPOTHESIS TESTING FOR DEVELOPED MODEL

Hypothesis	χ^2	DF	*p*-value	RMSEA	CFI	Estimated number	*t*-value	Decision
H1	240.	1	0	0.046	0.	0.55	7.89	Support
H2	320.	1	0	0.044	0.	0.54	4.95	Support
H3	393.	1	0	0.053	0.	0.60	6.97	Support
H4	351.	1	0	0.051	0.	0.36	4.22	Support
H5	265.	9	0	0.041	0.	0.68	6.99	Support
H6	155.	6	0	0.042	0.	0.91	11.7	Support
H7	357.	1	0	0.045	0.	0.69	3.75	Support
H8	317.	9	0	0.032	0.	0.68	4.15	Support
H9	218.	8	0	0.040	0.	0.72	5.56	Support
H10	102.	5	0	0.039	0.	0.92	3.66	Support

IX. CONCLUDED REMARKS

In conclusion, when operating in competitive markets implementation of LP practices for managing MET models appears to be more beneficial than costly, thus implementing LP practices may be able to enhance the productivity of MET model. In markets where competitive intensity is high, companies need to understand the relative influence of implementing LP practices considered in this paper; therefore the developed assessment tool presented is a helpful tool that enables mangers of MET system to understand such influences.

Results of this research are based on only one respondent from each company. Thus, the respondent's feedback may not reflect company policy or the view of other management level employees. Such personal bias may particularly affect. The study was conducted in a single country, Jordan. The restriction of the data collection to a single country limits the generalization of the results. Thus, although we can argue that the theoretical model would hold in additional markets, future research can adequately address this issue. Future research could investigate other lean production areas, such as quality and productivity improvement and measures, production and inventory control, shop floor management, product design and development, supplier relationship etc

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