Jordan Journal of Business Administration, Volume **18**, No. **2**, **2022**

The Application of Lean Principles and DMAIC Approach to Improve Maintenance Performance in Jordanian Industry: Baraka Pack Jordan Company As a Case Study

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ABSTRACT

Manufacturers are constantly trying to achieve the best productivity in order to preserve their position among their competitors and enhance the confidence of their customers. Once machines breakdown, the process of production is disrupted, which results in a great loss. To avoid such losses, DMAIC approach was applied to reduce the total time of breakdowns during manufacturing. This study was conducted in Baraka Pack Jordan in Al-Hassan Industrial Estate (HIE), where the required data for this study was collected. Then, the analysis of breakdowns was carried out in order to find out the root causes. Necessary maintenance actions were recommended and carried out. The results of this study show that the total breakdown hours for each machine during the study period (before and after DMAIC and lean principles' implementation) were reduced between 71.0% and 79.1%, while the average breakdown time per month was reduced by about 59.4%.

Keywords: Maintenance, DMAIC approach, Lean method, Breakdown, Baraka Pack Jordan Company.

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Received on 7/10/2020 and Accepted for Publication on 18/3/2021.

تطبيق مبادئ العجاف ونهج DMAIC لتحسين أداء الصيانة في الصناعة الأردنية: شركة البركة كحالة دراسية

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ملخص

يحاول المصنعون باستمرار تحقيق أفضل إنتاجية من أجل الحفاظ على مكانتهم بين منافسيهم وتعزيز ثقة عملائهم. بمجرد تعطل الآلات، تتعطل عملية الإنتاج، مما يؤدي إلى خسارة كبيرة. لتفادي مثل هذه الخسائر، تم تطبيق نهج DMAIC لتقليل الوقت الإجمالي للأعطال في أثناء التصنيع. أجريت هذه الدراسة في حزمة مصانع البركة في منطقة الحسن الصناعية (HIE)، حيث تم جمع البيانات المطلوبة لهذه الدراسة، وبعد ذلك، تم إجراء تحليل الأعطال من أجل معرفة الأسباب الجذرية ومن ثم التوصية بإجراءات الصيانة اللازمة وتنفيذها. وأظهرت نتائج هذه الدراسة أن إجمالي ساعات الأعطال لكل آلة خلال فترة الدراسة (قبل وبعد تطبيق DMAIC ومبادئ العجاف) قد انخفض ما بين 71% و79.1%، بينما انخفض متوسط الانهيار شهريًا حوالي 59.5%.

الكلمات الدالة: صيانة، نهج DMAIC، الأسلوب الخالي من الهدر، الأعطال، شركة البركة.

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تاريخ استلام البحث 2020/10/7 وتاريخ قبوله 2021/3/18.

1. INTRODUCTION

The improvement of organizational efficiency of a company can be achieved in different ways. For example, Bashar et al. (2019) studied the impact of corporate governance on the efficiency of managing working capital in the manufacturing sector in Jordan. They concluded that the more experience the CEO has and the smaller the board size is, the better the governance of manufacturing companies in Jordan would be in managing their working capital efficiently with high profitability. Manufacturing companies in Jordan tend to ignore managing their working capital efficiently. Ahmad et al. (2019) investigated the impact of organizational structure on achieving competitive advantage in a field study on industrial and service establishments in Jordan. They recommended to avoid centralization of decision-making, to activate communication channels among administrative levels and to deal constructively with conflicts within the organization in order to increase the ability to make change and face challenges. On the other hand, Mothana et al. (2019) studied the impact of information technology on organizational performance in Jordanian public entities. Their results revealed that there are relationships among information technology dimensions as well as between information technology dimensions and organizational performance at the significance level of (0.05). In addition, the results showed that there is a significant positive impact of information technology on organizational performance.

Unlike these approaches, in this study, the reduction of waste in maintenance activities was studied through the application of lean principles and DMAIC approach.

Lean manufacturing aims at decreasing the cost and the lead time of production, which results in improving the overall efficiency. It was and is still being adopted by several automobile and manufacturing industries besides their suppliers. In a dictionary, the term "lean" means efficient and strong and it means fit and thin, which in turn means that this type of manufacturing results in that the needed organization's resources are fit, thin, efficient and strong (Al Mannai and Suliman, 2017). Accordingly, lean manufacturing will focus on waste elimination. Based on lean manufacturing approaches, there are different types of waste as specified by Toyota production scheme, which has been altered and prolonged. These types are; waiting, over-processing, motion, knowledge disconnection, defects, transportation, over-production and inventory. However, some tools, instruments and techniques may be used to aid the lean transformation of the organization, which include; preventive maintenance, reduction of batch size, stream mapping of the value, kanban, total productive maintenance, standard work, 5S, source quality and visual management (Habidin et al., 2017).

DMAIC methodology is a good approach for solving problems and can be integrated with the lean concept. It was noticed that DMAIC has been applied in three areas. In the first area, DMAIC has been applied in manufacturing sectors (Jirasukprasert et al., 2014; Ghosh and Maiti, 2014; Kumaravadivel and Natarajan, 2013). Applying DMAIC in manufacturing sectors enabled:

1. Jirasukprasert et al. (2014) to increase the sigma level from 2.4 to 2.9.
2. Ghosh and Maiti (2014) to achieve a significant reduction in gas defects and an annual cost saving up to INR 16 million.
3. Kumaravadivel and Natarajan (2013) to increase the sigma level from 3.49 to 3.65 and to increase the process capability from 1.163 to 1.22; so, the rejection of components was reduced from 50 to 32 and the percentage of rejection was reduced from 6.94 to 4.69.

In the second area, DMAIC has been applied in service sectors (Mayer, 2014; Yu and Ueng, 2012; Antony et al., 2012). In the third area, DMAIC has been applied in unconventional sectors (He et al., 2014; Franchetti and Yanik, 2011).

Suresh (2015) used six-sigma DMAIC methodology for defects' reduction in manufacturing of automobile piston ring. Using the six-sigma method, the rejection percentage was reduced by 13.2% from the existing 38.1% of rejection. Further improvement in the rejection percentage is expected in the long run after the continuous implementation of all the solutions.

In a study entitled "Thinking lean: Implementing DMAIC methods to improve efficiency within a cystic fibrosis clinic", Chad Smith et al. (2011) could decrease the non-value-added time (defined as the time a patient spends alone in an examination room), without altering the time that providers spend caring for a patient by applying lean methods. Their research efforts increased the available capacity by 500 patient visits per year, representing an additional revenue of over US$165,000 annually with no additional administrative costs incurred.

Overall Equipment Effectiveness (OEE) is an effective tool in identifying bottlenecks. It can be integrated with other continuous improvement tools and techniques. Yogi et al. (2020) used OEE through lean six-sigma DMAIC and the resulting framework was applied to a bottleneck process for a multi-national semiconductor company in the Philippines. The conceptual framework covered the integration of various approaches proven by related studies, such as Total Productive Maintenance (TPM), FMEA, Visual Management, Mistake Proofing, Single Minute Exchange of Dies (SMED) and DOE. Results showed that overall OEE increased from 68% to 87%, which indicated a 30% improvement. In terms of hit rate, it increased from 35% to 66%, which is a 31% improvement. The highest improvement contributor was the performance component with an improvement equivalent to 24% in OEE % and 67% improvement in hit rate. The conceptual framework derived from this study can be a guide in improving bottleneck processes for similar industries.

Nallusamy (2016) studied the implementation and effectiveness of an independent system of maintenance in a machine shop to improve OEE using TPM and 5S tool through a systematic approach. The research dealt with the aspects of quality, availability and performance that were utilized in order to calculate the value of a machines' OEE. TPM methods; for example, 5S, cleaning and preventive maintenance had been effectively implemented on the machines. The results of this research revealed that OEE improved in the horizontal and vertical machining centers by 5% and 7%, respectively.

There are different waste forms, like; unwanted items, defects, scraps, raw substances besides broken and aged tools. Work activities standardization is considered the major waste abolition principle through stations for work. Another study was conducted using TPM implementation on the line of a foundry. A modern maintenance method associated with TPM was provided. The results of this study illustrated the effectiveness of TPM in maintenance action enabling; therefore, operational costs are reduced and productivity is increased (Habidin et al., 2017).

Martomo and Laksono (2018) developed a study aiming at applying TPM using OEE to measure the equipment effectiveness and find the root problem cause to present suggestions for improvement and breakdown hour reduction. The results obtained explained that the average OEE value in the machines was 79.96%, which is considered low; i.e., lower than 85%. The reason of the low OEE value is the performance rate with a percentage factor of six big losses at decreased speed losses of 17.303% of the whole time loss. Suggested actions for improvement were: autonomous maintenance implementation, as well as presenting training for maintenance technicians and operators.

Ramakrishnan and Nallusamy (2017) developed and implemented a TPM lean method in order to decrease the overall lead time and hours of a breakdown in the manufacturing industry with the objective of minimizing hours of the breakdown in a foundry by 30%. The problem of breakdown has been identified in the industry and it explained that the major contributor to the hours of breakdown was at the casting manufacturing level in the foundry. Then, the proper solution was suggested to decrease the overall lead time and breakdown hours. The results of the study showed that about 20 % of immunization in the hours of breakdown had been achieved after lean tool implementation in the industry.

Nallusamy (2017) investigated the manufacturing losses through prioritizing the root causes using a Pareto diagram and aimed to suggest a proper solution to overcome problems that occurred in the manufacturing process. The author carried out a case study in order to enhance the manpower and machine tool utilization through initiating the practices by TPM which would form a lean manufacturing base. Moreover, TPM assists to adopt a systematic work inside the factory that decreases the losses in the activity of production, increases the life of equipment, organizes the behaviors of employees and ensures utilizing equipment effectively. The results showed that there were decreases in rework time, setup time, breakdown losses, as well as cycle time. Moreover, the overall effectiveness of the equipment was increased by 15%.

The aim of this study is to reduce the breakdown time to about 60% as set by the top management of the factory. So, DMAIC and lean approach were applied in this research.

A tool called "Value Stream Mapping (VSM)" (Nallusamy, 2016) was used to recognize the problem. The upcoming VSM phase is employed to remove the actions with no value and decrease the lead time accordingly (Nallusamy, 2016). This tool is also employed in the system's bottleneck diminishing to obtain an ongoing procedure flow.

This study is conducted according to the methodology and tools provided *via* lean manufacturing and DMAIC approach. On the other hand, it will be applied to the Jordanian industry to eliminate the waste time of breakdown. The process of permitting the machine operating until failure occurred followed by repair is referred to as breakdown maintenance. The management and the engineers then start advancing a novel approach for maintenance, which is required for breakdown failure elimination. Consequently, predictive maintenance and preventive maintenance were considered to reduce machine breakdown.

2. DMAIC Methodology

DMAIC methodology for process improvement by reducing defects comprises five phases (Figure 1). Each phase can be explained as follows:

Define: The define phase has three main parts. The first part is to determine the customer (internal and external) and carry out a voice of the customer (VOC) analysis to find out the service, product or process features, which are critical to the customer's view of quality, called critical to quality (CTQ). The second part is performing an SIPOC (supplier, input, process, output and customer) analysis to know the suppliers to the process under study, the inputs provided by those suppliers, very high level of abstraction of process flowchart under study, the process outputs and finally identify the customers or market segments for the outputs. The third part is detailed process flowing; similar to the high-level process flow, but each process section is mapped in more detail. Finally, formulate and introduce problem statement, project scope and team goals.

Measure: The second phase of the DMAIC is to measure the current performance of the process and detect the factors that affect the behavior of the process. Process definition and data collection plan build validity and consistency into data. Data reflects process performance and provides insight into the process. The goals of the measure phase is to quantify and confirm the problem, to clarify or revise the problem statement, to identify the steps in the current process and to determine the desired outcome. Moreover, input measures indicate supplier performance and correlate to output measures. Process measures are internal to the process and include key control elements for improving the output measures. Output measures are used to determine how well customers' CTQs are being satisfied.

Analyze: This phase analyzes the data collected in the measure phase to identify the potential root causes of the problem. Several quality tools are used to determine root causes and their corresponding effects on the problem, such as Pareto diagram, cause-and-effect analysis, five-why analysis and failure modes' and effects' analysis. The outputs of this phase demonstrate the root causes that most likely affect process variation.

Improve: The improve phase consists of developing and selecting the optimum or near-optimum solutions for the best results and most robust performance. There are many tools used for the improvement process, such as brainstorming and benchmarking. Four steps are required to do the improve phase:

1. Generating improvement alternatives or concepts.
2. Evaluating and selecting solutions capable of improving the process.
3. Performing cost/benefit analysis.
4. Validating the improvement.

Control: In this phase, the improvements are ensured to be standardized, revised, documented and institutionalized. The new process is monitored *via* your defined metrics and other measurement tools to assess its capability over time and the high-level process flow, but each process section is mapped in more detail. Finally, formulate and introduce problem statement, project scope and team goals.

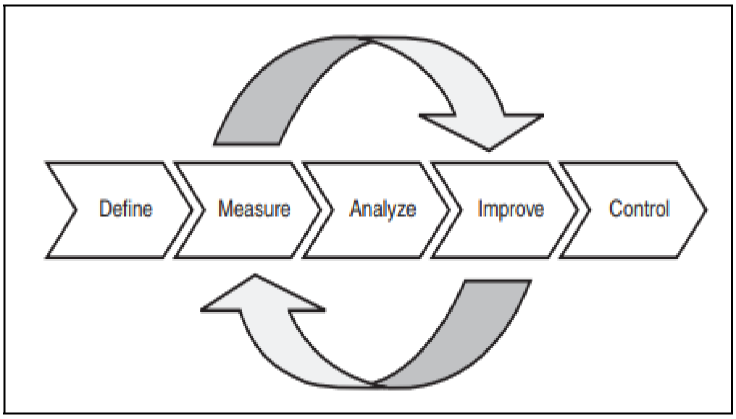

Figure (1)
Process phases of DMAIC (Habidin et al., 2017)

The methodology of DMAIC utilizes a process-step structure. Where steps are sequential, some activities from different steps can occur concurrently or iteratively. Deliverables' process for a given step should be finished before formal gate review approval. Figure 2 includes a high-level process flow of the DMAIC approach through its steps.

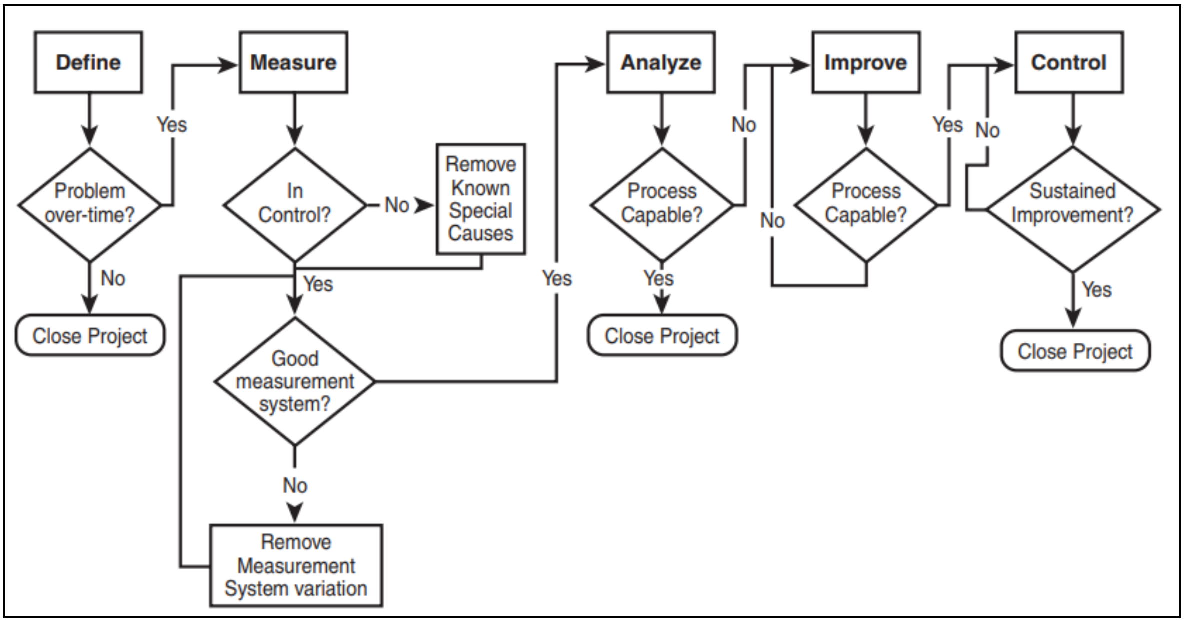

Figure (2)
High-level DMAIC process flow (Habidin et al., 2017)

3. Case Study

3.1 Define Stage

This study was made in Al-Baraka Pack Jordan Company, which locates in Al-Hassan Industrial Estate (HIE). This factory is specialized in the manufacture and printing of corrugated carton boxes. The existing system in the factory was studied and the required information was collected. Ten months were spent to collect the desired data (from January 2018 to October 2018) by conducting discussions with the senior employees and top management and getting an access to factory records. The collected data is shown in Table 1. It can be noticed that the average breakdown hours in the months from January to October are 16.136 for mechanical and electrical activities. The top management of the factory set an objective to reduce the breakdown hours to about 60% per month.

Moreover, it can be noticed from this table that the average mechanical breakdown hours per month amounted to 14.193 hours and the average electrical breakdown hours per month amounted to 2.006 hours. The average total breakdown hours per month amounted to 16.136 hours.

It is clear that the average mechanical breakdown hours per month are higher than the average electrical breakdown hours per month. The increment in the average of electrical, mechanical and total breakdown hours per month during the period from June 2018 to October 2018 occurred due to the increment in the production rate, which led to an increase in the load on different machines as well as in the average breakdown hours.

Table (1)

Collected breakdown data from January to October 2018

Month	**Mechanical breakdown hours**	**Electrical breakdown hours**	**Total breakdown hours**
January	5.50	0.00	5.50
February	1.50	0.33	1.83
March	9.17	4.40	13.57
April	37.33	0.00	37.33
May	7.90	0.33	8.23
June	26.70	6.00	32.07
July	38.83	9.00	47.83
August	3.83	0.00	3.83
September	6.00	0.00	6.00
October	5.17	0.00	5.17
Total hours	141.93	20.06	161.36
Average (breakdown hours/ month)	14.193	2.006	16.136

Figure 3 shows the total breakdown hours, their average and the targeted value by the top management of the factory.

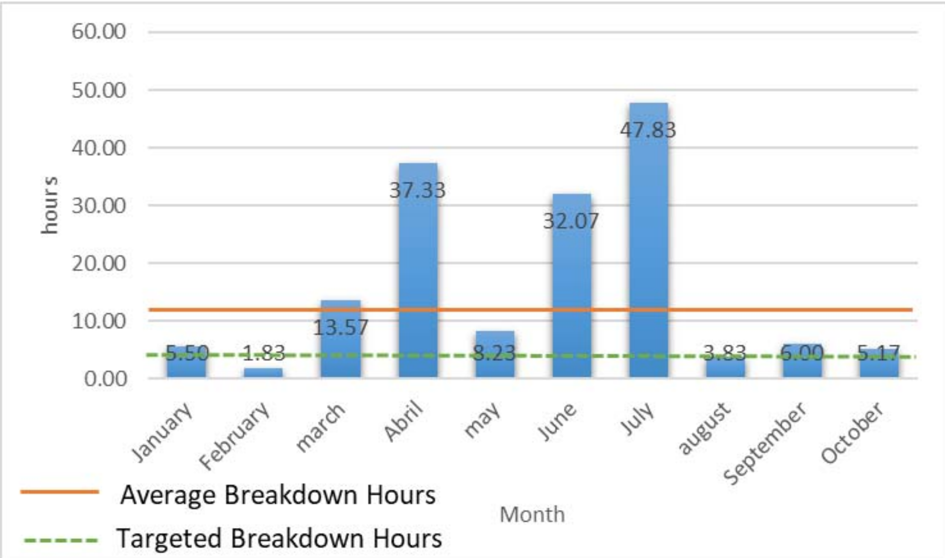

Figure (3)
Total breakdown hours/month, their average and the targeted value by the top management of the factory

3.2 Measure Stage

It was noticed in the previous sub-section that the average breakdown hours were very high when compared to the desired target determined by the factory top management. To reduce the average breakdown hours and be closer to the average breakdown hours, which was set by the factory's management, the TPM method was applied. Therefore, the breakdown hours for each machine from January 2018 to October 2018 were calculated, according to formula 1. The results obtained are listed in Figure 4.

Total Breakdown Hours = Sum of Breakdown Hours for all Months …. (1)

Figure 4 shows the total breakdown hours per machine from January 2018 to October 2018. Generally, the root cause of the high breakdown hours for machines that have the serial numbers (1, 2, 3, 6, 7, 9, 15, 18 and 20) should be determined to reduce the average breakdown hours for the factory. Thus, the breakdown analysis should be conducted to find the root cause of the breakdown hours for these machines.

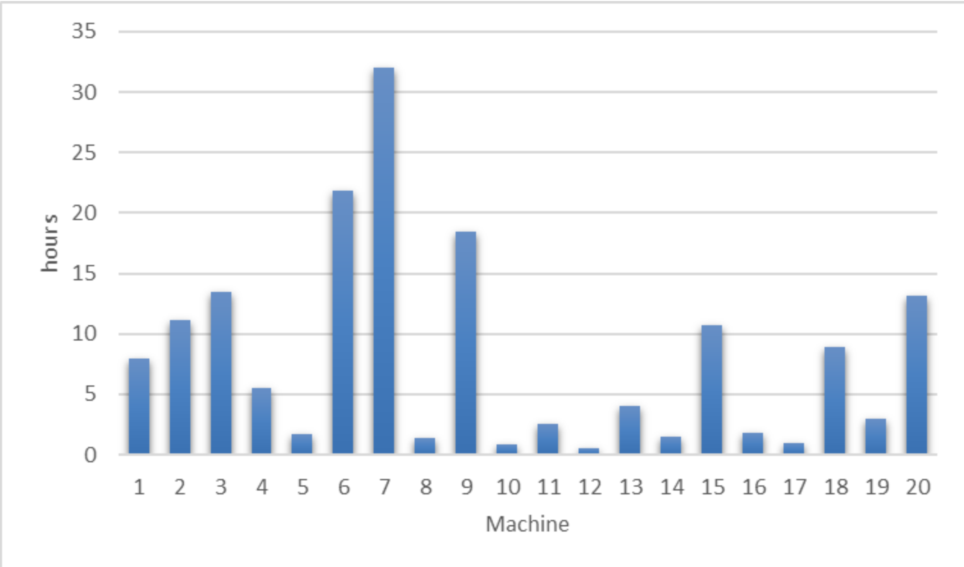

Figure (4)
Total breakdown hours/machine (mechanical and electrical breakdown)

3.3 Analyze Stage

The analysis was carried out for machines that have the highest breakdown time because reduction or elimination of the significant breakdown time of these machines will be reflected positively on the company’s productivity. Pareto diagram was used to evaluate the frequency of machine breakdown. One of the most common observations forms of the Pareto principle is the 80/20 rule. This rule states that 80% of the "outcomes" come from 20% of the "inputs". The 80/20 rule proposes that a large improvement in performance and quality can be achieved by focusing on those problems that have the highest breakdown time.

In this study, Pareto diagrams were constructed for the machines that have higher breakdown hours, which are; (1, 2, 3, 6, 7, 9, 15, 18 and 20). Figures 5 and 6 show examples of Pareto diagram.

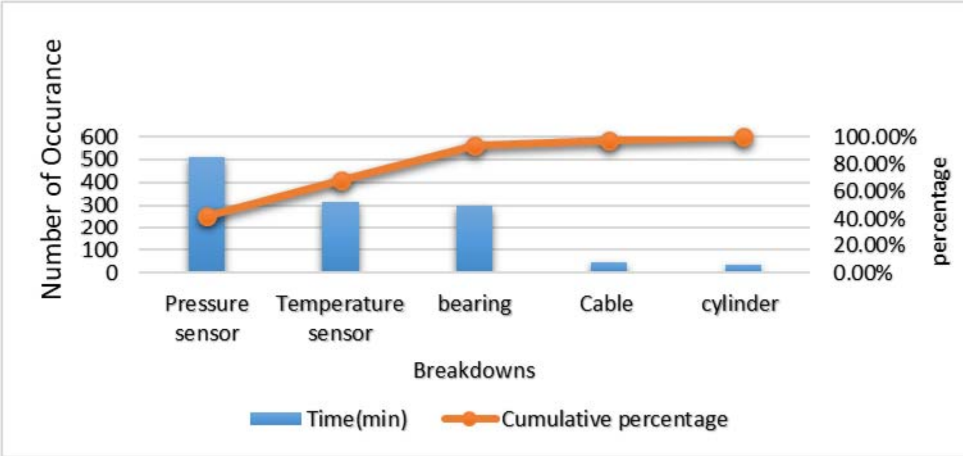

Figure (5)
Pareto diagram for breakdown analysis (machine 7)

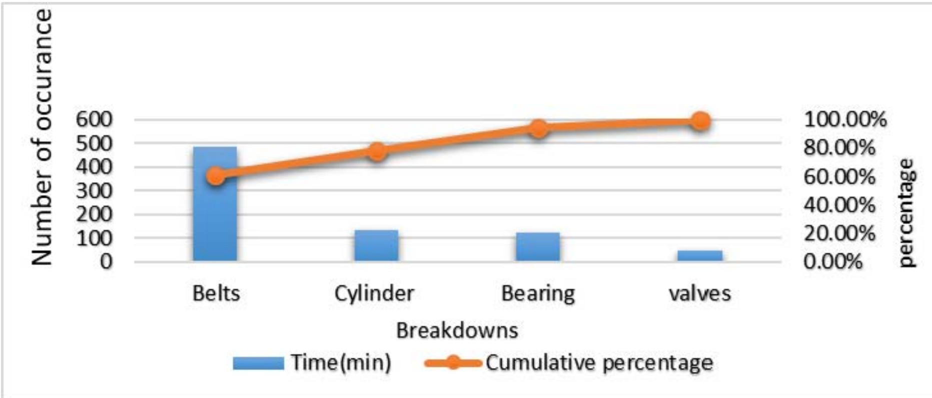

Figure (6)
Pareto diagram for breakdown analysis (machine 20)

After applying the 80/20 rule, the following points can be concluded:

1. The bearing and piston problems are the most common causes of the breakdown of machine no.1
2. The bearing problem is the most common cause of the breakdown of machine no.2
3. The change oil problem is the most common cause of the breakdown of machine no.3.
4. The cylinder problem is the most common cause of the breakdown of machine no.6.
5. The pressure and temperature sensors problems are the most common causes of the breakdown of machine no.7.
6. The sensors and valves problems are the most common causes of the breakdown of machine no.9.
7. The cylinder problem is the most common cause of the breakdown of machine no.15.
8. The bearing and piston problems are the most common causes of the breakdown of machine no.18
9. The cylinder and belt problems are the most common causes of the breakdown of machine no.20.

Constructing the cause-and-effect diagram (Figure 7), it was concentrated on the machine part of the program, as it has a considerable effect on productivity.

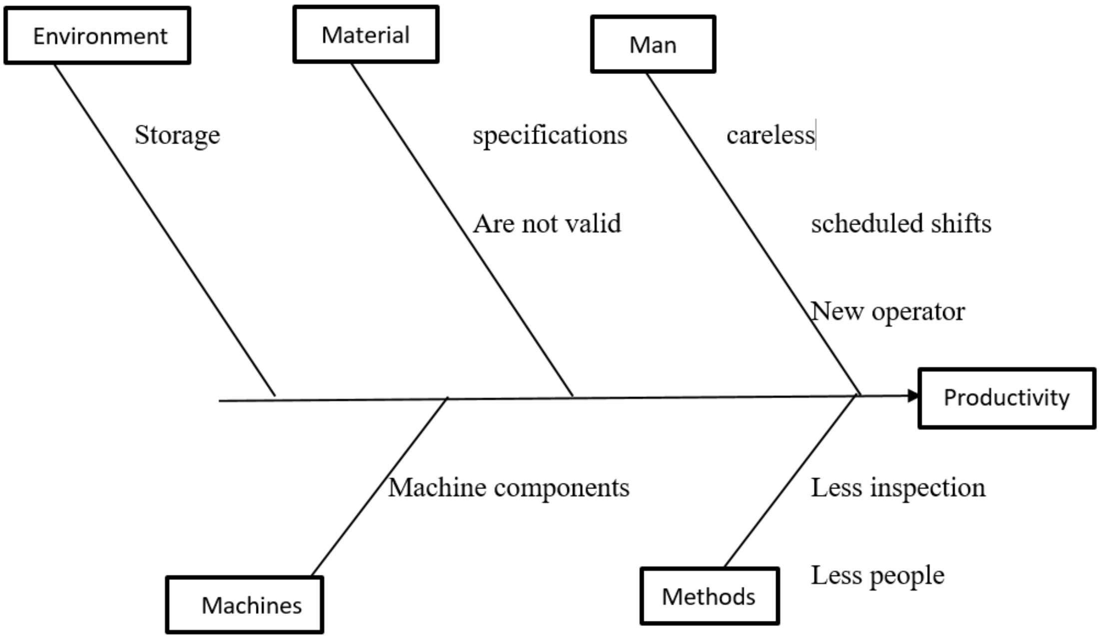

Figure (7)
Cause-and-effect diagram for the current status of the factory after consulting with specialists

3.4 Improve Stage

Based on what has been discussed in the analyze stage, the main breakdown causes are identified, while in this stage, maintenance actions are to be recommended. The recommended actions were based on the proactive methods in maintenance, like preventive maintenance, predictive maintenance, corrective maintenance and autonomous maintenance. Table 2 includes the different corrective maintenance actions for the machines that have the highest breakdown hours.

Root causes of each breakdown (Table 2) are determined after discussing them with engineers and technicians in the factory. Ccorrective maintenance actions were suggested to control and reduce the breakdown hours in the factory after discussing them with the responsible staff.

Studying carefully the information in Table 2, it can be noticed that the same problems are repeated in different machines, like the failure of different types of belts and bearings. Therefore, it was suggested to the top management to provide the factory with high-quality spare parts to increase the availability of these parts and to make regular check of them.

Table (2)
Breakdown report

Machine number	Machine Name	Breakdowns	Root cause (s)	Recommended action	Maintenance Type
1	Roll holder	Piston	Wear	Regular check and lubrication Providing sufficient spare parts	Preventive and predictive (Daily and weekly check)
		Bearing	Corrosion, fatigue, overheating, excessive load	Use of the suitable load and cooling system Use of lubrication	Preventive and predictive (Daily and weekly check)
2	Greasing machine	Bearing	Corrosion, fatigue, overheating, excessive load	Use of the suitable load and cooling system Use of lubrication	Preventive (Daily, weekly and monthly check)
3	Printer (four colors)	Change of oil	Oil type	Changing the oil type and regular check for oil level	Predictive and predictive (Daily, weekly and monthly check)
6	Greasing machine	Cylinder failure	Side loading	Use of lubrication	Corrective and predictive (Daily, weekly and monthly check)
7	Printer (one color)	Pressure sensor	Frequent damage	Changing the sensor Changing of control voltage or supply voltage board	Corrective (Daily check)
		Temperature sensors	Frequent damage	Changing the sensor Changing of control voltage or supply voltage board	Corrective and predictive (Daily, weekly and monthly check)
9	Old slitter-scorer machine	Valves	Excessive temperatures or pressures	Changing the damaged valves with a good valve type	Corrective and predictive (Daily, weekly and monthly check)
		Sensors	Frequent damage	Changing the sensors Changing of control voltage or supply voltage board	Corrective and predictive (Daily, weekly and monthly check)
15	Tying/ Packingg machine	Cylinder failure	Side loading	Use of lubrication and regular check	Preventive and predictive (Daily, weekly and monthly check)

18	Slotter machine	Piston	Wear	Regular check and lubrication Providing sufficient spare parts	Preventive and predictive (Daily, weekly and monthly check)
		Bearing	Corrosion, fatigue, overheating, excessive load	Use of the suitable load and cooling system Use of lubrication	Preventive and predictive (Daily, weekly and monthly check)
20	Printer (four colors)	Belt failure (different types)	Excessive load, weak drive structure or under-tensioned belt	Use of a good type of belts Belt alignment to be monitored regularly	Preventive and predictive (Daily, weekly and monthly check)
		Cylinder failure	Side loading	Proper installation	Daily, weekly and monthly check)

3.5 Control Stage

3.5.1 Preventive Maintenance (PM) Action

PM is defined as a schedule used as a planned maintenance technique and aims to prevent both failures and breakdowns. In addition, the main goal of PM is to avoid equipment failure before it really takes place. PM was designed to enhance and preserve equipment reliability, as it recommends replacing worn equipment before they really fail. So, PM actions include different activities, such as lubrication and complete or partial overhauls in determined periods, in addition to equipment checks and oil changes.

Moreover, workers should record the deterioration of equipment, so that they can repair or replace worn equipment before system failure. As well, the best program of preventive maintenance would prevent the failure of all equipment before it takes place. It has long-term benefits, such as enhancing the reliability of the system, reducing the replacement cost, reducing breakdown time and better management of spare parts' inventory.

In this research, the preventive maintenance action included check sheets that were prepared to help the maintenance engineer as well as the technicians. These check sheets of preventive maintenance should be filled by operators on a daily and weekly basis. The different suggestions of preventive maintenance have been provided to the factory as checklists. Most of the breakdown time is actually spent on changing the belts and bearings; so, it was suggested to check and lubricate these parts on a weekly basis. The suggestions included a recommendation to the factory to bring spare parts with higher quality, especially for bearings and belts, as well as to clean the different machines and lubricate some moving parts every day.

3.5.2 Predictive Maintenance (PdM) Action

The aim of PdM is to predict the failure of equipment that might take place as well as to prevent the occurrence of failure by some maintenance actions. Prediction of the occurrence of future failure permits maintenance to be planned before the occurrence of failure.

The advantages of this maintenance are reducing the maintenance time, reducing the loss in production hours and reducing the spare parts' cost as well as supplies' cost. In this study, a checklist for predictive maintenance was prepared. This maintenance checklist was suggested to be carried out on a monthly basis by the facilitator head in the factory.

4. Results and Discussion

Based on the recommendations in the improve and control phases, corrective actions were implemented in the period from November 2018 to April 2019. The comparison of the average breakdown time for the machines before and after the implementation of the corrective actions is shown in Figure 8. It is clear that there is a reduction of 59.5% in the total average breakdown time per month after the implementation of the suggested corrective actions.

This results explain the effect of the implementation of corrective actions on the factory's performance and profits. It can be also noticed that these results agreed with the results of the study of Ramakrishnan and Nallusamy (2017), in which breakdown hours were reduced by 20% after the implementation of TPM. On the other hand, the results of the current study did not agree with the results of the study conducted by Martomo and Laksono (2018), because of differences in the methodology of the study that aimed at applying TPM using OEE to measure the equipment effectiveness.

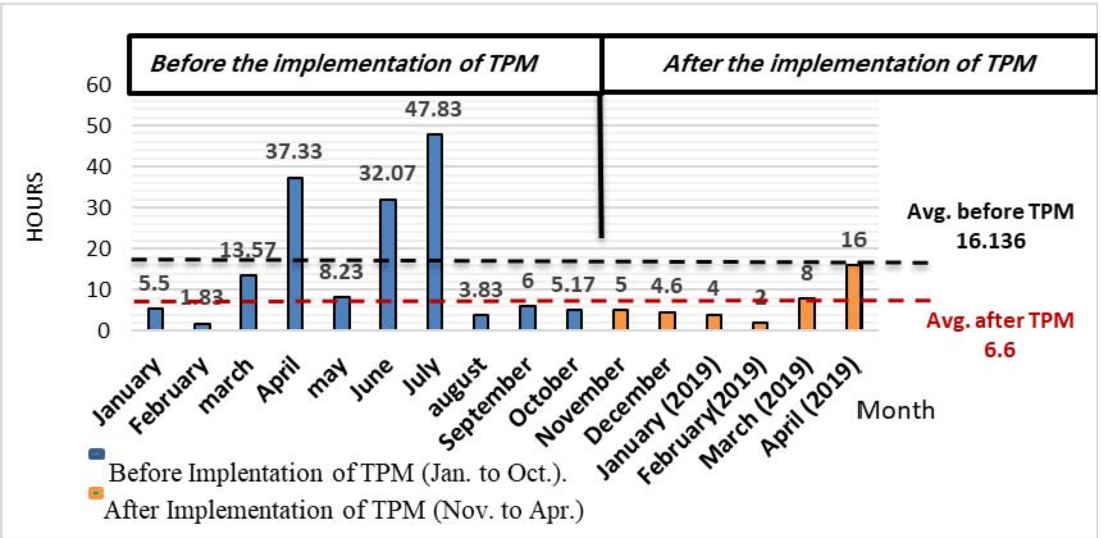

Figure (8)

Total loss in hours before and after applying the recommended actions

Table 3 shows the results of average breakdown time before and after the implementation of corrective actions for the machines that had the highest breakdown hours before the implementation. The table shows that average breakdown time was reduced for all the selected machines. Also, it shows how the implementation of corrective actions had a positive effect on the factory performance, where the total average breakdown hours were reduced to be (33.53 hours) compared to (137.7 hours), which means a percentage of breakdown hours' reduction for these machines of (75.65)%, which is considered a good improvement.

Figure 9 shows a comparison chart for breakdown analysis for the selected machines before and after the implementation of the corrective actions.

Table (3)
Results of average breakdown time before and after implementation of TPM

Machine's serial number	Machine's name	Total breakdown minutes before applying TPM	Total breakdown minutes after applying TPM	% of hrs. reduction for each machine after the implementation of TPM
1	Roll holder	480	100	79.1
2	Greasing machine (A)	670	164	75.5
3	Greasing machine (B)	810	212	78.2
6	Printer (four colours) (A)	1310	320	75.5
7	Printer (four colours) (B)	1920	404	78.9
9	Printer (one colour) (A)	1104	320	71.0
15	Die cutter, automatic	644	164	74.5
18	Auto sticker machine	534	116	78.3
20	Compressor	790	212	73.1
Total (Minutes)		8262	2012	75.65
Average Breakdown (Minutes)		826.2	335.33	59.4
Total (Hours)		137.7	33.53	
Average Breakdown (Hours)		13.77	5.59	

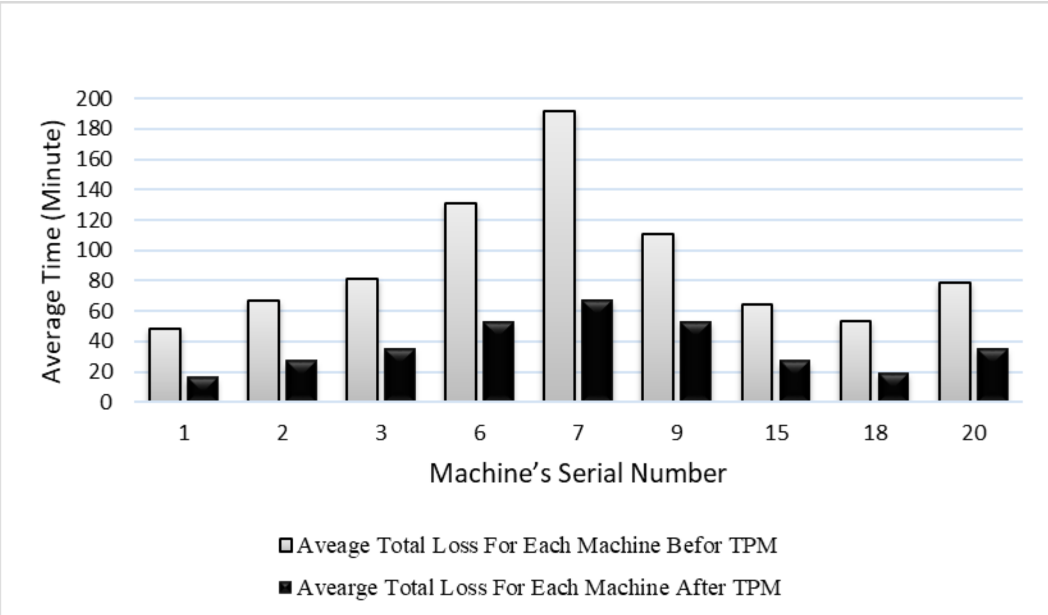

Figure (9)
Comparison chart for breakdown analysis

5. Conclusions and Recommendations

This study has been performed using DMAIC approach and tools provided by lean manufacturing to reduce the wasted breakdown time in Al-Baraka Pack Jordan in Al-Hassan Industrial Estate (HIE). Different actions were recommended after the root causes of breakdown were determined. Based on the results of this study, the following conclusions were made:

1. The effectiveness of DMAIC and lean principles' implementation was found by comparing the average breakdown hours per month before and after the implementation of the corrective actions, where the reduction was 59.5%.
2. The average breakdown of each machine during the period of study (before and after DMAIC implementation) was reduced between 71.0% and 79.1% with an average of 75.65%, although the average breakdown time for all machines was reduced by 59.5%.
3. DMAIC proved to be a good tool for solving maintenance problems by integrating it with lean manufacturing principles.
4. The corrective maintenance approach in the company is replaced by DMAIC approach, since it proved to be more effective.
5. The DMAIC proactive approach has an important role in developing the work culture of employees in the industry field.

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