Assessment of OEE and Evaluation of a Filling Line Performance by using ARENA Simulation

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Abstract

The purpose of this paper is to evaluate and improve the performance of filling machines for the food manufacturing line based on discrete-event simulation. A simulation model was built to assess machines breakdowns using purely historical data provided by the operations and analyzed for the first time over a period of 28 months. The data of MTBF and MTTR have been extracted in order to replicate the existing machines, breakdown occurrences, failure, and repair distributions of machines. Further, the statistical distributions have been applied in the first model and the data were also used to calculate the components of the overall equipment effectiveness (OEE) of the filling line to identify potential areas of improvement. The models were built using the Arena Simulation Package to represent and animate tools of the filling line machines with a series of elements in order to improve the display for the human interface. The simulation was validated taking into consideration the replicating of the business model in a computer system with totally risk-free and create "what if" scenarios to test strategic changes and extract results. The outcome of the simulations was the basis of OEE analysis and assessment. The operation of the B-production line is not as expected, the availability was very low compared to the target 90%, and equipment's failure losses present 64% of total availability losses while the remaining 36% is related to production losses. A validated simulation model can be a useful tool in the maintenance decision-making process.

Keyword: MTBF, MTTR, TPM, OEE, Simulation and Modelling

الملخص

الغرض من هذا البحث هو تقييم وتحسين أداء آلات التعبئة لخط تصنيع الأغذية على أساس محاكاة الأحداث المنفصلة. حيث تم إنشاء نموذج محاكاة لتقييم أعطال الآلات باستخدام البيانات التاريخية البحتة المقدمة من العمليات وتحليلها لأول مرة على مدار 28 شهرًا. تم استخراج بيانات MTBF و MTTR من أجل التكرار للآلات الموجودة وتكرار حدوث الأعطال والفشل وإصلاح توزيعات الآلات. علاوة على ذلك، تم تطبيق التوزيعات الإحصائية في النموذج الأول واستخدمت البيانات أيضًا لحساب مكونات الفعالية الكلية للمعدات (OEE) لخط الملء لتحديد مجالات التحسين المحتملة. تم بناء النماذج باستخدام حزمة Arena Simulation Package لتمثيل وتحريك أدوات آلات خط التعبئة بسلسلة من العناصر من أجل تحسين العرض لواجهة المستخدم. تم التحقق من صحة المحاكاة مع الأخذ في الاعتبار تكرار نموذج الأعمال في نظام كمبيوتر خالٍ تمامًا من المخاطر وإنشاء سيناريوهات "ماذا لو" لاختبار التغييرات الإستراتيجية واستخراج النتائج. كانت نتيجة عمليات المحاكاة هي أسس تحليل وتقييم OEE. عملية خط إنتاج B-production كانت ليس كما هو متوقع، حيث كانت

Availability منخفضة جدًا مقارنة بالهدف وهو 90٪ ، تمثل خسائر فشل المعدات 64٪ من إجمالي خسائر Availability بينما تتعلق نسبة 36٪ المتبقية بخسائر الإنتاج. يمكن أن يكون نموذج المحاكاة الذي تم التحقق من صحته أداة مفيدة في عملية اتخاذ قرارات الصيانة.

1. Introduction

In today's competitive manufacturing environment, achieving safe and maximum equipment performance is essential for manufacturing organizations [1]. Achieving world-class status requires the implementation of multiple complementary and proven management strategies and programs [2]. The use of an effective maintenance management program is important to reduce the risks associated with equipment's safety and reliability, reduce waste and run an efficient, continuous manufacturing operation; it also avoids heavy losses and low market share due to a poor product safety and quality [1][2][3]. The idea behind effective maintenance programs and intelligent inspections is to keep ahead of maintenance, by knowing where all the problem areas are, the easiest way to combat such issues, and most importantly carrying out preventive work on a regular basis based on intelligent information. Moreover, data collected from inspection and maintenance reports can be embedded in decision-making tools/techniques to help understanding behaviour of machinery and possible causes of breakdowns occurrence [4]. Therefore, maintenance plays an important role in organizations competitiveness under increasing international pressure [5]. Maintenance management and design for maintainability and reliability are considered strategic factors for success in today's dynamic environment [1]. One of the world-class manufacturing programs organizations used during the quality revolution is total productive maintenance (TPM). TPM is considered an effective strategic improvement initiative for improving quality in maintenance engineering activities, optimizing equipment effectiveness, eliminating breakdowns and promoting autonomous maintenance [6][7]. Nakajima [12] identified three main objectives of TPM: zero defects, zero breakdowns and zero accidents. Overall equipment effectiveness is a measurement tool used in identifying and measuring the productivity of machines in industry. It is a performance measurement tool that presents an updated status of any product with the least details in terms of calculations. It helps identify potential losses and how corrective actions could be used to reduce it. Such measurements could be done on machines, men and materials leading to higher productivity [8]. In this paper, the OEE was measured by collecting data of the three OEE variables, availability, performance and quality over a period of 28 months. The data required for the OEE measure was collected on a daily basis by maintenance staff responsible for the continuous and correct operation of the packaging production line. The production line operates in three eight-hour shifts during each work day and pauses during the weekends. The weekend is usually spent on maintenance of the line. Breakdown maintenance and preventive maintenance policies are used to ensure desired reliability levels. Breakdown maintenance refers to the maintenance strategy when the repair is done after the equipment failure/stoppage or upon the occurrence of severe performance decline [9]. This strategy has the disadvantages of high repair cost, excessive time loss due

to maintenance and troubleshooting and spare parts problems [10]. Preventive maintenance comprises periodic maintenance activities undertaken on the machines or the entire production line. It involves a well-defined set of tasks, such as inspection, cleaning, lubrication, adjustment, alignment, etc., at specific points on the line [10]. The analysis of failure and repair data of the production line was carried out, this data contributes to OEE losses related to Equipment failures/breakdowns. It is also included in TPM initiatives and activities associated with planned maintenance, Autonomous maintenance and quality maintenance [2][11]. Statistical distributions of failure and repair parameters (i.e. TBF and TTR) were estimated using Input analyzer template within Arena package aided by Minitab. The statistical distributions were included in a developed model to simulate machine failures of the aseptic liquid packaging line. The process of production line modelling includes gathering available information from historical data as well as expert knowledge and experience, as it is vital when building useful models and helps build a greater understanding of machine breakdowns.

2. The Overall Equipment Effectiveness OEE

2.1 Constituents of OEE

The total productive maintenance (TPM) philosophy, launched by Nakajima [12] lead to a metric called overall equipment effectiveness (OEE). The six big losses used in OEE calculation defined by Nakajima are usually categorized into three main categories based on aspects of loss as shown in Figure 1.

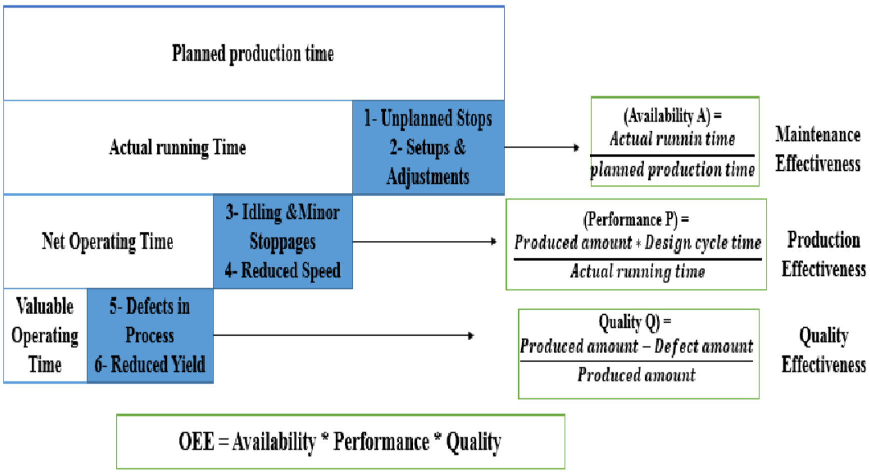

Figure 1. The OEE measurement tool.

2.2 Definition of OEE

2.2.1 Breakdowns

These Equipment failure losses are categorized as time losses when productivity is reduced and quality losses caused by defective products.

2.2.2 Set-up/adjustment time

Set-up/adjustment time losses result from downtime and defective products that occur when the production of one item ends and the equipment is adjusted to meet the requirements of another item.

2.2.3 Idling and minor stop

Idling and minor stop losses occur when production is interrupted by a temporary malfunction or when a machine is idling.

2.2.4 Reduced speed and small stop

The losses refer to the difference between the equipment design speed and the actual operating speed.

2.2.5 Reduced yield

Reduced yield occurs during the early stage of production from machine start-up stabilization.

2.2.6 Quality defects and rework

Quality defects and rework are losses in quality caused by malfunctioning production equipment due to rework, volume losses, expense losses and time losses required for corrective action.

The six significant losses are explained by three performance aspects:

I. **Availability or availability efficiency**
II. **Performance rate or performance efficiency**
III. **Quality rate or quality efficiency**

- **Availability (A): The first component of the OEE measure is concerned with the first two losses and is defined as:**

$$Availibilty\ rate\,(A) = \frac{Operating\,time\,(hrs)}{Loading\,time\,(hrs)} *100$$

Operating time = Loafing time - downtime

- **Performance (P): The second component of the OEE calculation is the performance efficiency (PE) where the actual amount of production is measured. This component is affected by the third and fourth losses i.e. speed losses.**

$$Performancy\,effici.\ (P) = \frac{Theoretical\ \ cycletime * Acualoutput\,(units)}{Operating\ time\ (hrs)}$$

- **Quality (Q): The third component of the OEE calculation is the quality rate (QR), which is the proportion of good production to the total production volume. It is concerned with the final two losses.**
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$$Quality\ rate\,(A) = \frac{(Total\ production - Defect\ amount)}{Total\ production\ (units)} * 100$$

Measurement using OEE can be used at different levels within the manufacturing environment since it measures the initial performance of an entire manufacturing plant, which creates a benchmark for management in the decision-making [13]. It has its strength in the way it integrates different important aspects of manufacturing into a single measurement tool. The perspectives integrated into the OEE tool are the maintenance effectiveness, production efficiency and quality efficiency [14]. The actual availability, performance efficiency and quality rate measures, together with the complete OEE figure for each day and month are shown in Figures 2 and 3 respectively.

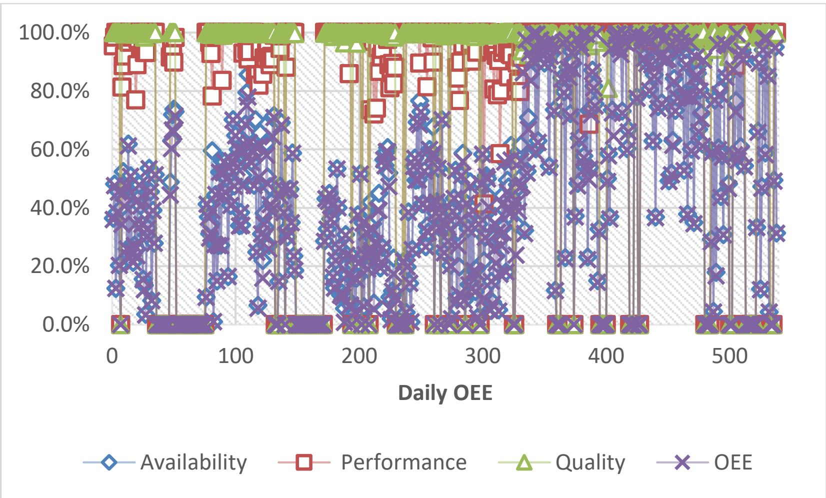

Figure 2. The actual availability, performance and quality rate measures, together with the OEE figure for each day

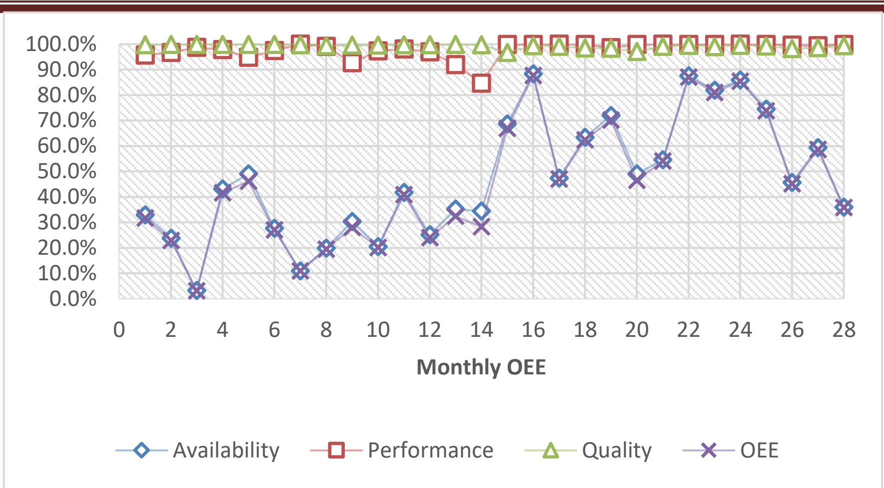

Figure 3. The actual availability, performance and quality rate measures, together with the OEE figure for each month

TABLE 1: Second experiment results

Month	Availability	Performance	Quality	OEE
1	0.3287	0.9568	0.9976	0.316528
2	0.2375	0.9679	0.9983	0.228243
3	0.0316	0.9873	0.9987	0.031079
4	0.4305	0.9792	0.9983	0.4157
5	0.4898	0.9480	0.9986	0.461974
6	0.2764	0.9747	0.9983	0.269642
7	0.1095	0.9994	0.9975	0.109369
8	0.1981	0.9918	0.9942	0.193972
9	0.3031	0.9268	0.9966	0.280338
10	0.2040	0.9736	0.9969	0.200588
11	0.4172	0.9807	0.9978	0.408167
12	0.2511	0.9697	0.9969	0.239542
13	0.3525	0.9199	0.9983	0.323716
14	0.3448	0.8469	0.9980	0.28287
15	0.6864	0.9991	0.9675	0.669059
16	0.8824	0.9993	0.9934	0.876784
17	0.4733	0.9997	0.9916	0.469645
18	0.6339	0.9983	0.9843	0.623415
19	0.7189	0.9857	0.9842	0.702142
20	0.4898	0.9982	0.9708	0.465725
21	0.5460	0.9995	0.9907	0.540684
22	0.8760	0.9983	0.9951	0.870504
23	0.8188	0.9985	0.9902	0.810232
24	0.8588	0.9998	0.9951	0.854331
25	0.7440	0.9987	0.9928	0.737912
26	0.4565	0.9964	0.9829	0.451316
27	0.5933	0.9935	0.9859	0.585478
28	0.3598	0.9994	0.9942	0.358078
Average	0.3999115	0.9737793	0.9939202	0.388749

The following observations can be made:

- **The availability of the line is about 40%, which is far from the target's availability of 90% of the production line. These losses are connected to machines failures as well as production stoppages. The production losses are related to material shortages, power outages and other problems related to upstream processes which indicate the need for better planning.**
- **The performance of the line is 97.3%, which is coincided with the target's performance of 95%.**
- **The quality rate of 99.3% approximates the target (99.9%) for the production line.**
- **The overall equipment effectiveness is low (38.8%) considering the target of 85%, the main causes are excessive breakdowns and production downtime due to material shortages or other problems related to the upstream process.**
- **Table 2 shows the total downtimes related to planned maintenance, equipment downtime and production downtime on a yearly basis. Data show a notable reduction in equipment's failure losses linked with planned maintenance increment; the planned maintenance losses are categorized into (preparation for production with 7.4%, cleaning in place CIP with 26.4%, production tests with 0.1% and line-planned maintenance with the highest percentage 66%).**

Table 2. Annually production and downtime of production line

Year	Shift time	Planned maint.	Equip. D.T	Prod. D.T	Run time	Tot. Prod.	Good Prod
2012	429120	29688	201906	90474	107062	13782722	13762453
2013	149280	67614	32431	8981	40254	5155906	5128996
2014	355200	185182	30409	50488	89121	11854438	11769887
Grand Total	933600	282484	264746	149943	236437	30793066	30661336

3. Field failure data

The time-between-failure (TBF) of particular equipment at the machine or line-level is defined as the time that elapses from the moment the equipment goes up and starts operating after a failure, until the moment it goes down again and stops operating due to a new failure under the applied maintenance policy. The TBF excludes the weekends and breaks, during which the line is not operating. On the other hand, the time-to-repair (TTR) of failed equipment is the time that elapses from the moment the equipment goes down and stops until the moment it goes up and starts operating again. Both the records for the production line are in minutes. The failure frequency was evaluated by means of a Pareto chart as shown in Figure 4 using the software package MINITAB, the most frequent failures are observed at the Cardboard packer

CBP machine amounting to 24.8% of all failures, the second frequent failures are at the filling machine standing for 22.9% of all failures. The cap applicator failures are ranked in the third position with 22.2% of all failures.

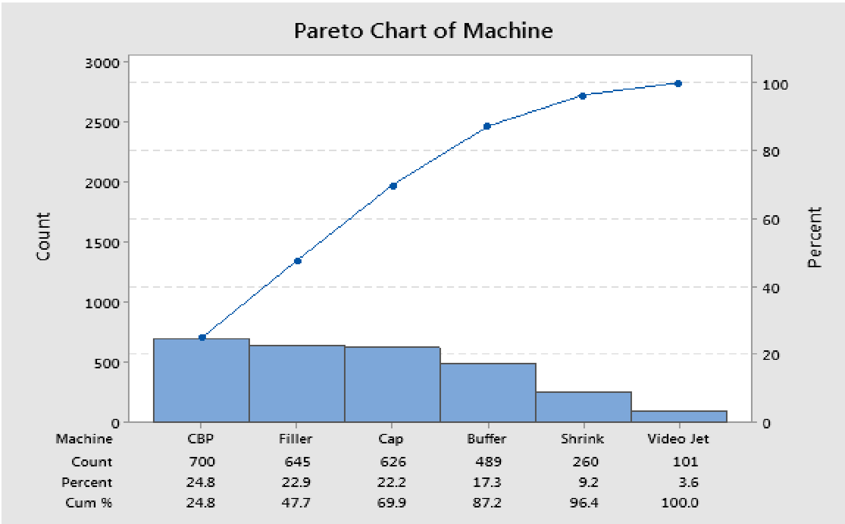

Figure 4. Pareto chart for all failures of B-production line

It is observed that four machines out of six contribute to more than 80% of total line failures, based on this information. The causes that initiate these failures for these machines should be thoroughly analyzed. Maintenance staff generally records causes of failures in hand-written work orders and should be motivated to be more specific and divide them into categories and store them in a PC. This helps managers to analyze the causes and take appropriate decisions. Descriptive statistics of the basic features of the failure and repair data for TBF and TTR are presented in Table 3.

Table 3. Descriptive statistics for the machines and the entire line

Variable	Count	Mean	StDev	CV	Median	Min	Max	Skewness	Kurtosis
TBF Filler	645	633	714.6	1.13	415	23	7939	4.11	25.75
TBF Videojet	101	4998	8802.7	1.76	1476	75	57281	3.36	13.87
TBF Buffer	489	1066	2572.8	2.41	460	174	33044	8.23	80.34
TBF Cap	626	749	1348	1.80	427	68	13885	6.27	45.44
TBF CBP	700	662	864.4	1.31	435	73	11669	6.90	66.28
TBF shrinker	260	1755	2709.3	1.54	812	78	22628	4.16	23.48
TBF line	2821	120	301	2.52	68	5	9574	17.59	450.62
TTR Filler	645	113	136	1. 2	60	3	960	2.39	8.74

TTR Videojet	**101**	**58**	**94.8**	**1.65**	**15**	**3**	**480**	**2.72**	**7.72**
TTR Buffer	**489**	**34**	**43.2**	**1.28**	**18**	**3**	**360**	**2.95**	**12.34**
TTR Cap	**626**	**55**	**63.2**	**1.14**	**34**	**3**	**470**	**2.69**	**9.85**
TTR CBP	**700**	**47**	**56**	**1.20**	**30**	**3**	**480**	**3.73**	**20.63**
TTR Shrinker	**260**	**19**	**22.4**	**1.17**	**10**	**3**	**152**	**2.50**	**8.11**
TTR line	**2821**	**59**	**83**	**1.40**	**28**	**3**	**480**	**2.84**	**9.20**

In the B-production line, there is a failure every 120 minutes (or 2 hours) on average. The coefficient of variation CV is bigger than one for machine and line indicating a high variability of variables. The mean time to repair TTR is 59 minutes (about one hour) with high variability since (CV) is bigger than one. The minimum mean TBF is observed at the filling machine with 633 minutes whereas the maximum mean TBF is at the video jet (date printer) with 4998 minutes. On the other side, the maximum mean TTR was noted at the filling machine with 111 minutes and the minimum TTR was at the shrinker machine with 22 minutes.

Box plots for TBF and TTR of the machines for the production line are shown in Figures 5 and 6.

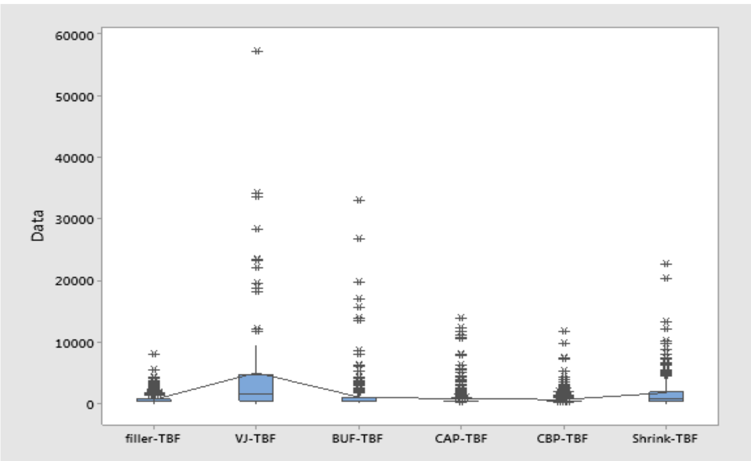

Figure 5. Box plots for TBF of the machines

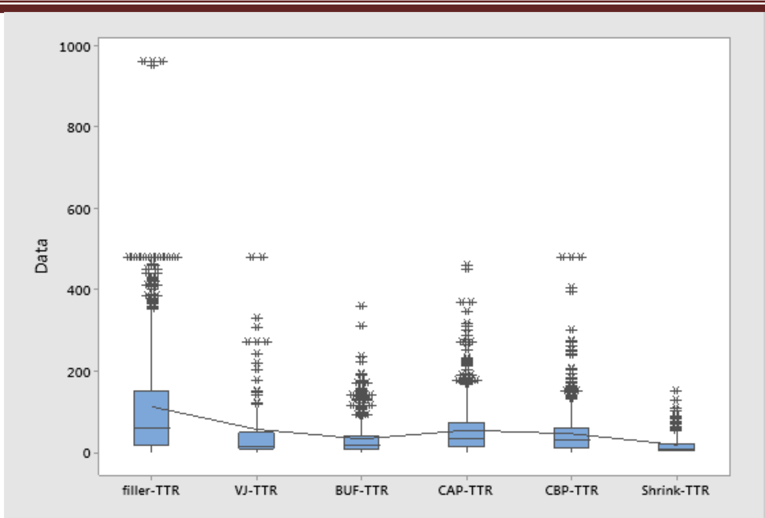

Figure 6. Box plots for TTR of the machines

The graphical representation of TBF for filler, buffer, cap applicator and cardboard packer machines has many outliers. It should be noted that these machines have no theoretical distribution to represent TBF. An empirical distribution may provide a better representation in this situation. The alternative way to show the empirical distribution is to divide the data and making distribution fit for each data subset. However, the empirical distributions were selected here if the theoretical distributions didn't give a good fit. Both TBF and TTR for machines have positive skew values, meaning that TBF and TTR presented borderline mode median mean.

4. Simulation models

Simulation models were also developed for the entire line and for filling machine, the developed simulation models rely on the generation of random number streams. Therefore the results generated by the models are dependent on distribution (i.e. theoretical or empirical distributions). One hundred replications were carried out enabling the effects of the distribution to be determined in order to increase the effect of confidence in the results. Figure 7 shows the entire modelled system for the production line.

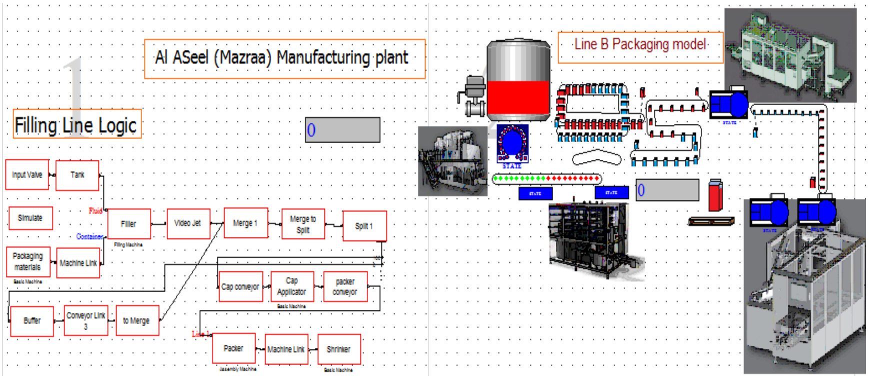

Figure 7. Entire production line basic model

The Arena simulation package has a template called Output analyzer. It provides an easy-to-use interface that simplifies data analysis, allows viewing, analyzing output data quickly and easily. Output data files were created using (statistics module) from advanced process modules template. The output analyzer gives a variety of options to analyze output data (i.e. bar chart, histogram and other statistical analysis options).

Before conducting simulation experiments, the user must decide a number of factors including:

- **The input parameters**
- **Model run length and time units**
- **Number of statistical replications**

Once the base model was ready (i.e. validated and verified by experts), the failure and repair data distributions (MTBF and MTTR) could be applied to the machines within modules reliability. The MTBF and MTTR distribution Expressions were derived from input analyzer aided by Minitab Distribution Identification. The results of the model are shown in tables 4 and 5 for the production line machines.

TABLE 4. Number and duration of machines failures

Machine	Avg. Num. Of Failures	Min. Avg.	Max. Avg.	Avg. Total Time Failed	Avg. Total time lost
Filler	57	41	73	6549.42	8147.08
Video Jet	10	0	21	510.19	510.19
Buffer	38	9	57	1289.89	1289.89
Cap Applicator	55	28	87	2998.22	5656.37
C. Packer	61	30	80	2757.27	3053
Shrinker	20	1	43	382.03	382.03

TABLE 5. Reliability parameters TBF and TTR for production line

Machine	Average TBF	Average TTR
Filler	657.18	117.53
Video Jet	4284.61	52.99
Buffer	1163.79	33.90
Cap applicator	748.77	55.64
Cardboard packer	666.38	45.27
Shrinker	2138.29	19.39

The results of Classical Confidence Interval on Mean are shown in table 6 where these results were generated using Output Analyzer.

TABLE 6. Classical C.I. Intervals Summary

Identifier	Avg.	StDev	0.95 C.I	Min.	Max.	No Of OBS
Filler TBF	646	723	18.9	23.1	7890	5604
VJ TBF	3640	5090	324	75	36000	952
Buffer TBF	1030	2070	65.9	174	33000	3807
CAP TBF	718	1180	31.5	68.1	13800	5418
CBP TBF	651	733	18.4	73.3	11600	6084
Shrinker TBF	1830	3170	139	81.7	37300	1989
Filler TTR	117	149	3.91	3	1930	5583
VJ TTR	53.5	81.3	5.17	3	852	951
Buffer TTR	34.1	47.6	1.51	3	733	3804
CAP TTR	55.3	62.8	1.67	3	1040	5414
CBP TTR	45.3	47.6	1.2	3	446	6078
Shrinker TTR	19.2	24.2	1.06	3	249	1988

4.2 Second experiment

For this experiment, scheduled tasks will be added to the filling machine to see the number of tasks carried out and the collated time lost due to these maintenance issues. It also shows the number of failures and corresponding parameters (tasks). The results are shown in table 7.

Table 7. Second experiment results

Description	Value
Daily tasks carried out	25
Average daily task time	120.14
CIP tasks carried out	12
Average CIP task time	210.06
Weekly tasks carried out	4
Average weekly task time	240.6
Total tasks time	4202
Total time blocked	8745.3
Average Number of failures	42
Total time failed	4839.62
Mean TTR	118.02
Mean TBF	938.55
Total time lost	13584.92

The results show that failure occurrences have decreased compared to the first experiment. However, the influencing parameters usage rates did not correlate at all to the failure occurrences. This brought to light that, failures, obviously did not occur within a fixed time and that failure could have occurred for different reasons at any time based on MTBF mode.

5. Conclusion

This study carries out an analysis of overall equipment effectiveness within a beverages production line to identify the critical points of the production process that need actions to improve the operations of the line. The OEE metrics aim to improve competitiveness in any manufacturing industry by increasing

productivity and ensuring sustained profits. Furthermore, OEE is a part of Total Productive Maintenance (TPM) methodology that is a long-term strategic initiative; TPM implementation requires a long-term commitment to achieve the benefits of improved equipment effectiveness. As a result, OEE is the core metric for measuring the success of the TPM implementation program [3]. The operation of the B-production line is not as expected; the availability was very low compared to the target 90%, equipment's failure losses present 64% of total availability losses while the remaining 36% is related to production losses. Therefore, the availability component should be improved immediately. In addition, to avoid the inconvenient impact of the failures on the production process, it is strongly recommended to upgrade the operation management, i.e. TPM program, parts replacement decisions, training programs for technicians/operators, spare parts requirement, etc. A simulation model is also presented in this study, which represents packaging beverages production line subject to failures, the model is based also on the Arena platform, offers less computational burden and is less sensitive to data error. The model was designed to be compared with the real packaging line. Two experiments were carried out using simulation; the first model was used to represent the production line with failure and repair distributions applied to machines. The second experiment included three influencing factors (scheduled tasks) to study their effect on machines breakdown. A discrete event simulation is a useful tool for looking at different scenarios; a validated model can be an extremely useful tool in the maintenance decision-making process. The aim was to build a simulation model that can be used as a tool in order to understand machine breakdown occurrences. However, like all techniques, there are limitations as i.e. Simulation model building requires special expert training and simulation modelling and analysis can be costly with the results of simulation involved in many statistics. One of the main disadvantages of simulation is the existence of programming errors [15]. A simple inputted piece of data that is incorrect can alter the results of the simulation drastically giving the wrong results. The simulation model can be integrated with the maintenance and production strategies of the organization to give the best possible results. There are two types of integration, the hard integration aspects are aided by technology and computers, while the Soft integration aspects are to do with humans the mental approach of the workforce making it intangible [16][17]. The two types of integration are directly related to prevention, i.e. they aid unobstructed prevention of loss and thereby increase efficiency. Therefore, the Arena simulation or any other modeling simulation tool can be fully integrated with management and manufacturing philosophies like total productive maintenance TPM that talk about the need for a combined effort from industrial assets and industrial labor. [16][17]. Training and empowering the staff creates awareness and promotes a sense of responsibility from their side. This is one of the key factors crucial to successful TPM implementation; these factors include top management commitment, strategic planning, cross-functional teams, Autonomous Maintenance, maintenance improvement and equipment design improvements. Simple quality tools like 5

whys or fishbone diagrams for complex systems could be used in acquiring possible reasons for the loss-related events which could be caused by machines, humans, processes, materials or methods and eradicate these losses. Qualitative research can be carried out in gathering data based on interviews or through questionnaires addressed to operators and the entire management teams to investigate the implementation of manufacturing techniques and philosophies within the manufacturing plant under study or within various food and beverage industries in Libya. OEE has evolved to include other production losses that were not originally included. This has led to the development of new terminologies that come up in literature and in practice like (TEEP, PEE, OPE, OAE and OFE) based on the type of production losses included, adoption of these measures gives management complete information for well-informed decision making. Furthermore, research may be done to explore the dynamics of translating equipment effectiveness or loss of effectiveness in terms of cost, production system operator's main intention is to optimize the profitability of the production system and not the availability of the production system. Thus, the cost translation of OEE will have more significance to management.

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