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Availability analysis of a 750 ton modern injection molding machine

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Abstract
Injection molding is a plastic forming process used in the production of most plastic parts (about 70%) in automobile industries. The manufacturing industry has gone through significant changes in the recent years. For a good manufacturing plant, the most recommended thing is quality, efficiency, machines availability and operating cost. The aim of this study is to determine the molding machine availability and its overall equipment effectiveness. In carrying out this work, raw data was obtained from Spefas Engineering services Co., Ughelli, Delta state. The data was subsequently processed to provide the required data for the calculation of availability and Overall equipment effectiveness.
The result generated yielded machine availability of 87.67% and the overall equipment effectiveness of 67%, as well as other useful parameters inclusive. In the recent times a remarkable improvement has taken a toll in maintenance management of the physical assets and productive systems to reduce wastage of energy and resources. Owing to this fact, the organization should introduce a maintenance continuously. Improvement in maintenance will help to improve and sustain machine availability which is one of the performance evaluation metrics that are most common and popular system to improve and increase both the quality and productivity in the production industries.

Keywords: Improve, performance evaluation, productivity

1. Introduction
With the introduction of a repair capability that will restore a system to an operative state, an alternative measure of system performance is availability. Availability depends on both reliability and maintainability. To predict the system availability both the failure and the repair probability distribution must be considered Ebeling (1997).
Thus availability can be defined in the line of thoughts of Ebeling (1997) as “the probability that a system or component will perform its required function at a given point in time or over a stated period of time when operated and maintained in a prescribed manner”. When being quantified, availability applies the rules of probability theory for its establishment. It can also be viewed as the probability that a system is operational over a given point in time or as the percentage of time over some interval in which the system is operational. There are several ways of assessing system availability.
Forms of availability include; inherent availability, achieved availability, operational availability, generalize operational availability, used availability,
Availability depends on both reliability and maintainability Telsang (2011), Very short preventive maintenance intervals resulting from frequent down times have availability less than the inherent availability. As the preventative maintenance interval increases, the achieved availability will reach a maximum point and then gradually approach the inherent availability. Dormant failures are often caused by corrosion or mechanical fracture, but the dominant cause of dormant failure is latent manufacturing defects. If inspection requires some downtime, there is a tradeoff between inspection downtime (detection) and restoration of failures.
In some situations we may specify or solve for availability directly. In such cases, there are obvious trade-offs between reliability and maintainability. If specifications of the reliability and maintainability are parts of the design process, an opportunity may exist for trade-offs between these two parameters based on the availability specification.

1.1 Overall equipment effectiveness (OEE)
Overall equipment effectiveness (OEE) is a set of metrics to monitor and evaluate the utilization of the facility.

Developed in mid 1960 by Seiichi Nakajima, OEEhas become an accepted industrial tool measure and evaluate plant floor productivity. OEE consists of three measuring factors i.e., Availability, Performance and Quality. These factors help to measure plant's efficiency and effectiveness. It also categorizes key productivity losses that crept into the manufacturing process.

OEE provide scope for manufacturing companies to improve their processes and in turn ensure consistency, quality and productivity. By definition, OEE is a product of Availability, Performance and Quality.

Mathematically

OEE = Availability x Performance x Quality

Availability = OEE/(Performance x Quality)

1.2 Statement of the Research Problem

The ideal performance measures in injection molding machines tend to be distorted by irregularities caused by machine breakdowns, tool failure, preventive maintenance, raw material quality and a variety of other short term interruptions resulting to low equipment availability. This is a significant problem since it affects the true productive capacity of the injection molding machines. (Constant hazard failures) the rest of its life. The system availability predicts the actual running time with respect to the scheduled operating time.

Availability analysis is one of the most widely used techniques, wherever production is in effect. Therefore, to be able to determine Overall Equipment Efficiency, there exists a need to investigate the number of times the molding machine is available when its use is required vis-à-vis the quality of output in units of production. This can enable check maintenance, repairs and sustenance of the machine in order to achieve high productively when the production time is improved upon.

1.3 Aim and Objectives

The aim and objective of the study is:

- To carry out availability analysis of injection molding machine.
- To determine the number of productive hours of the molding machine
- To be able to know when break down occurs in the machine.
- Investigate quality output from the molding machine.
- To determine the up time and down time of the machine

1.4 Scope of the Study

This work focuses mainly on the Availability analysis of the molding injection machine in SPEFA Engineering services Co., Ughelli Plant. Raw Production key performance data from 2013 to 2015 were obtained and used for this work.

2. Literature Review

Availability is well established in the literature of stochastic modeling and optimal maintenance. Barlow *et al.* (1975) [2] defines availability of a repairable system as "the probability that the system is operating at time t". Blanchard (1998) [12] gives a qualitative definition of availability as "a measure of the degree of a system which is in the operable and committable state at the start of mission when the mission is called for at an unknown random point in time". Lie, Hwang *et al.* (1977) [13] developed a complete survey alone with a systematic classification of availability.

Availability measures are classified by either the time interval of interest or the mechanisms for the system downtime. If the time interval of interest is the primary concern, we consider instantaneous, limiting, average and limiting average availability. The afore-mentioned definitions are developed in Barlow and Proschan (1975) [2]. Lie *et al.* (1977) [13] and Nachlas (1998) [14]. The second primary classification for availability is contingent on the various mechanisms for down time such as the inherent availability, achieved availability, and operational availability. Blanchard (1998) [12], Lie *et al.* (1977) [13]. Mi (1998) gives some comparative results of availability considering inherent availability.

Availability considered in maintenance modeling can be found in Barlow et.al (1975) [2], for replacement models, Fawzi *et al.* (1991) [15] for an R - out – of – N system with spares and repairs, Fawzi *et al.* (1990) [16] for a series system with replacement and repair, for imperfect repair models, Murdock (1995) [17] for age replacement preventive maintenance models, Nachlas (1998, 1989) [14, 18] for preventive maintenance models and Wang and Pham (1996) for imperfect maintenance models.

Availability is used extensively in power plant engineering and manufacturing equipment.

2.1 An overview of the plastic molding section

In Spefas Engineering, Plastics molding machines of 750 tonnage and moulds are used to produce plastics crates in a very orderly manner. The designs are acquired from the client as per their need. Then, according to the design of the crates, moulds are procured. The main raw materials used for production is the plastic pellets called High Density Polyethylene (HDPE polymers) and the Master batches to give the desired color of the product.

In the firm, four units of CLF-750 and SM 750 injection molding machines arranged in parallel are used as shown in figure 1.

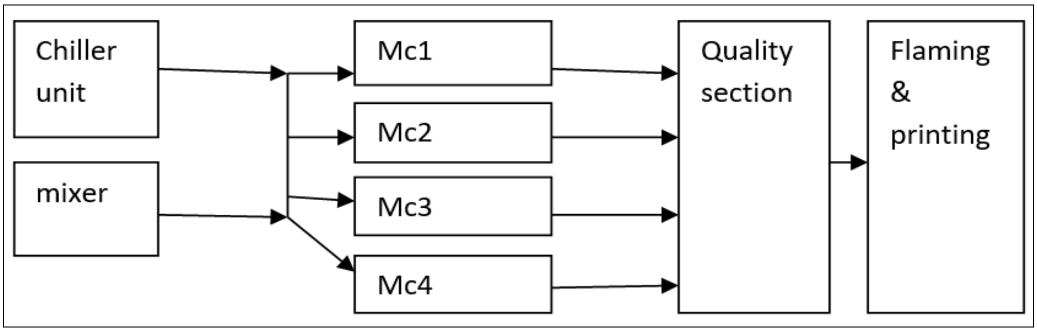

Fig 1: Arrangement of the production facilities

2.2 Manufacturing Process

The following steps are involved in the manufacturing of plastics crates;

- Pellets poured in hopper.
- Pellets fall into barrel by means of throat.
- Pellets are pressed to form solid bed. (air constrained out through hopper)
- Pellets are melted by mechanical shear between barrel and screw
- Melted plastic form shot in front of screw (screw moves back as plastic moves forward –reciprocating screw)
- Screw moves forward to infuse plastic into mould cavity.
- Part cooled and cements (next shot is made)
- Mould opens.
- Ejection pins push forward to eject part
- Mould retracts and Process begins once again.

2.2.1 Injection molding Process

Injection molding machines consist of a material hopper, an injection ram or screw-type plunger, and a heating unit. Also known as presses, they hold the moulds in which the components are shaped. Presses are rated by tonnage, which expresses the amount of clamping force that the machine can exert. This force keeps the mould closed during the injection process.

2.2.2 Hydraulic Machine

Hydraulic presses have historically been the only option available to molders until Nissei Plastic Industrial Co., LTD introduced the first all-electric injection molding machine in 1983.

Hydraulic machines, although not nearly as precise, are the predominant type in most of the world, with the exception of Japan.

2.2.3 Mechanical Machine

Mechanical type machines use the toggle system for building up tonnage on the clamp side of the machine. Tonnage is required on all machines so that the clamp side of the machine does not open (i.e. tool half mounted on the platen) due to the injection pressure. If the tool half opens up it will create flash in the plastic product.

2.2.4 Electric Machine

The electric press, also known as Electric Machine Technology (EMT), reduces operation costs by cutting energy consumption and also addresses some of the environmental concerns surrounding the hydraulic press. Electric presses have been shown to be quieter, faster, and have a higher accuracy; however the machines are more expensive.

2.2.5 Hybrid injection (sometimes referred to as "Servo-Hydraulic") molding machines claim to take advantage of the best features of both hydraulic and electric systems, but in actuality use almost the same amount of electricity to operate as an electric injection molding machine depending on the manufacturer and such machine is the CLF -750TX from Chuan Lih FA.

2.2.6 Injection molding cycle

The sequence of events during the injection mould of a plastic part is called the injection molding cycle. Fig 2 shows that the cycle begins when the mould closes, followed by the injection of the polymer into the mould cavity. Once the cavity is filled, a holding pressure is maintained to compensate for material shrinkage. In the next step, the screw turns, feeding the next shot to the front screw. This causes the screw to retract as the next shot is prepared. Once the part is sufficiently cool, the mould opens and the part is ejected.

2.2.7 Scientific versus traditional molding

Traditionally, the injection portion of the molding process was done at one constant pressure to fill and pack the cavity. This method, however, allowed for a large variation in dimensions from cycle-to-cycle. More commonly used now is scientific or decoupled molding, a method pioneered by RJG Inc. In this the injection of the plastic is "decoupled" into stages to allow better control of part dimensions and more cycle-to-cycle (commonly called shot-to-shot in the industry) consistency. First the cavity is filled to approximately 98% full using velocity (speed) control. Although the pressure should be sufficient to allow for the desired speed, pressure limitations during this stage are undesirable. Once the cavity is 98% full, the machine switches from velocity control to pressure control, where the cavity is "packed out" at a constant pressure, where sufficient velocity to reach desired pressures is required. This allows part dimensions to be controlled to within thousandths of an inch or better.

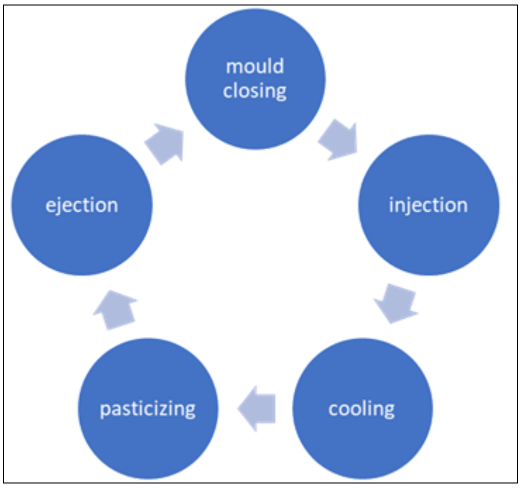

Fig 2: Injection molding cycle

3. Methodology

Three Availability matrices have been collected i.e. downtimes, uptime, scheduled time and production in units' data. For this purpose, interview of the molding machine operators has been done and discussed with the appointed engineer of that section.

From the Engineer, the Available time =24 hrs – (preventive maintenance scheduled time usually 1 hr + no of hrs power outage). Therefore, Available time for each machine is 23 hrs /day if no power failure occurs. The availability of the equipment is a function of the available time and down time. This can be enhanced by eliminating equipment breakdown, set-up/adjustment losses and other stoppages. It measures "productivity losses" from breakdown times and remaining time which is called "operating time". It is the ration of the operating time to planned production time. It represents the percentage of schedule time that the equipment is available to operate. It takes into account down time losses. In this work sample of data for the parameter to determine the availability of the 750 ton modern molding injection machine was collected. The parameters taking into account were chiefly the time and the available time.

The down time which is the integral composition of variety of factors was obtained by considering the equipment failure or breakdown, setups and change over time, material flow shortage time, meeting time and waiting time for operator. The earlier mentioned factors were further categorized into two *viz* a *viz*; Breakdown and setup/adjustment (plant operating time). The available time was obtained by taking into cognizance sum total of fully productive time, quality losses, speed losses, downtime losses and planned shutdown. These provide the means with which to determine the available time. It was further summarized to contain two broad factors namely; total Available and planned down time.

A set of data obtained here came from the equipment operational duration of 3 years period.

3.1 Sample size
The injection molding machines employed by SPEFAS Engineering, Ughelli plant are four of 750tons each and this study is based on one machine.

3.2 Method of data analysis
The following equations were used for calculating the equipment availability and overall equipment effectiveness.

3.3 MTBF
Mean Time between Failures is the average time the machine is operational without failures.

MTBF = Total operating time/ Number of failures

Also the operating time is determined by summing all the time segments representing when the injection molding equipment is producing crates, thus providing the equipment's average uptime.

3.4 MTTR- Mean Time to repair
Using the same formula above with the substitution of downtime for run time and again assuming an exponential distribution,

MTTR = Total Downtime/Number of failures 3.2

3.5 Availability
The well-known formula for availability,

Availability = MTBF / (MTBF + MTTR) 3.3

3.6 Performance Efficiency (PE)
Efficiency means doing things right. This means that the process of performing a task by a machine is carried out in the right measure. It is mathematically express as:

$$\text{Performance Efficiency} = \frac{\text{Output Processing Time (Processing Cycle Time)}}{\text{Target cycle Time}} \quad 3.4$$

3.7 Quality
Quality is express as:

$$\text{Quality} = \frac{good\ parts}{total\ production\ unit} \quad 3.5$$

3.8 Overall Equipment Effectiveness (OEE)
Overall equipment effectiveness is defined as the Algebraic product of overall availability, performance efficiency and quality. It can be expressed mathematically as:

Overall Equipment Effectiveness = Overall Availability x Performance Efficiency

x Quality x100 3.6

The above mathematical expressions are employed in chapter four to compute for the respective parameters.

4. Results Analysis
The raw data from the appendix results to the following tables 4.1, 4.2 and 4.3 with parametric measures according to the chronological order of the organization for three consecutive years. The raw data contain the downtimes, reasons for non-operative mode of the machine, production units (Good and rejects). The operating time of the machine was found by subtracting the down time from the available time (23 hrs/day). The number of failures was obtained by recording the number of failures experienced on the machine.

The good units were determined by subtracting the no of rejects from the total production units. All the variables were then organized into tables 4.1, 4.2, 4.3 for each year and finally summarized in one table 4.4 for the three years.

Table 1: Year 1 (2013) Key Performance Indicators

Month	Down time (hrs.)	Operating time (hrs.)	Number of times failed	Production units (Crates)	Rejects (Crates)	Good parts (Crates)
January	13 hrs.	171 hrs.	3 times	12577	21	12556
February	15 hrs.	100	3 times	7133	27	7106
March	5 hrs. 30mins.	149	1 time	11370	37	11333
April	Nill	115 hrs.	Nill	6707	7	6700
May	32 hrs.	178 hrs.	5 times	14393	61	14332
June	58 hrs.	126 hrs.	3 times	9518	51	9467
July	17 hrs.	167 hrs.	3 times	12173	29	12144
August	19:30 mins	18:30 mins	6 times	13133	90	13043
September	51 hr: 30 mins	178 hrs:30 mins	9 times	12838	86	12752
October	2 hrs. 30 mins	20 hrs:30 mins	1 time	9542	11	9531

November	3 hrs.	168 hrs.	3 times	11988	109	11879
December	14 hrs.	147 hrs.	1 time	10591	44	10547
Total	231 hrs.	1538 hrs: 30 mins.	38 times	131963	573	131390

$$MTBF = \frac{1538hrs: 30mins}{38\ times} = 40.5hrs$$

$$MTTR = \frac{231hrs.}{38} = 6.08\ hrs.$$

$$Availability = \frac{40.5}{46.58} = 0.85$$

Table 2: Year 2 (2014) Key Performance Indicators

Month	Down time (hrs.)	Operating time (hrs.)	Number of times failed	Production units (Crates)	Rejects (Crates)	Good parts (Crates)
January	44 hrs.	17 hrs.	1 time	14182	39	14143
February	8 hrs.	222 hrs.	Nill	16406	9	16397
March	28 hrs.	321 hrs.	2 times	25182	51	2513
April	24 hrs.	229 hrs.	Nill	15265	12	15253
May	16 hrs.	125 hrs.	Nill	10560	73	10487
June	12 hrs.	103 hrs.	1 time	5859	34	5825
July	6 hrs.	132 hrs.	1 time	9762	25	9737
August	4 hrs.	180 hrs.	Nill	13284	14	13270
September	39 hrs.	168 hrs.	Nill	12386	55	12331
October	17 hrs.	187 hrs.	3 times	13708	111	13597
November	31 hrs: 20 mins.	223:40 mins.	1	16207	62	1545
December	14 hrs.	124 hrs.	1	9065	36	9029
Total	243 hrs: 20 mins.	2031 hrs.	10 times	161866	521	161345

$$MTBF = \frac{2031\ hrs}{10\ times} = 203.1\ hrs.$$

$$Availability = \frac{203.1}{227.43} = 0.89$$

$$MTTR = \frac{243hrs: 30mins}{10} = 24.33\ hrs$$

Table 3: Year 3 (2015) Key Performance Indicators

Month	Down time (hrs.)	Operating time (hrs.)	Number of times failed	Production units (Crates)	Rejects (Crates)	Good parts (Crates)
January	52 hrs.	224 hrs.	Nill	16625	32	16593
February	6 hrs.	178 hrs.	2 times	12770	45	12725
March	9 hrs: 30 mins.	79 hrs: 30 mins.	1 time	6053	65	5988
April	9 hrs: 40 mins.	174 hrs.	1 time	12825	51	12774
May	47 hrs: 50 mins	159 hrs: 10 mins.	2 times	12095	31	12064
June	13 hrs.	123 hrs: 30 mins	Nill	9260	20	9240
July	4 hrs:30 mins	110 hrs.	1 time	8083	14	8069
August	34 hrs.	36 hrs.	Nill	2654	9	2645
September	4 hrs: 18 mins.	4 hrs: 42 mins.	Nill	3025	26	2999
October	12 hrs.	57 hrs.	3 times	6127	14	6113
November	2 hrs.	6 hrs.	Nill	4950	4	4946
December	1 hr.	45 hrs.	1 time	3324	11	3313
Total	195 hrs: 48 mins.	1196 hrs: 52 mins.	11 times	97791	322	97469

$$MTBF = \frac{1196.87\ hrs}{11} = 108.81hrs.$$

$$MTTR = \frac{195.8}{11} = 17.8$$

$$Availability = \frac{108.81}{126.61} = 0.86$$

Table 4: Summary of the results for the three distinct years

Month	Down time (hrs.)	Operating time (hrs.)	Number of times failed	Production units (Crates)	Rejects (Crates)	Good parts (Crates)
Year 1 (2013)	231 hrs.	1538 hrs:30 mins	38 times	131963	573	131390
Year 2 (2014)	243 hrs:20 mins	2031 hrs.	10 times	161866	521	161345
Year 3 (2015)	195 hrs: 48 mins.	1196 hrs: 52 mins.	11 times	97791	322	97469
Total	670 hrs: 08 mins.	4766 hrs: 22 mins.	59 times	391620	1416	390204

$$MTBF = \frac{4766.37hrs.}{59} = 80.8\ hrs.$$

$$MTTR = \frac{670.0033\ hrs.}{59} = 11.36\ hrs.$$

$$Availability = \frac{80.8}{92.16} = 0.877$$

$$Total\ good\ parts = 390204$$

The overall availability for the three years was computed on the integral result of the values of MTBF, MTTR from the table mentioned earlier using equation (1), (2) & (3).
Performance efficiency was calculated using equation (4), quality was obtained by the use of equation (5), while overall equipment effectiveness was obtained using equation (6) respectively all from chapter three.

$$Total\ good\ parts = 390204$$

Total production units (introduced part) = 391620
Total processing time = 4766 hrs: 22 mins
Total down time = 670 hrs: 08 mins

$$Performance\ efficiency = \frac{measured\ output\ pocessing\ time}{target\ output\ processing\ time}$$

Planned processing time = the target output cycle time of the process. The target output time for each day is 23hrs of operation per day. The machine worked for 94 days in 2013, 108 days in 2014 and 66 days in 2015 based on the client's schedule.

Therefore, the total number of days = 268 days.

$$Target\ cycle\ processing\ time = 23 \times 268 = 6164\ hrs.$$

The actual processing time is equal to the operating time of the machine in the processing.

$$Performance\ efficiency = \frac{4766.37}{6164} = 0.77$$

$$= 0.77$$

$$Quality = \frac{390204}{391620} = 0.996$$

$$= 0.996$$

$$OEE = 0.877 \times 0.77 \times 0.996 \times 100 = 0.67$$

$$= 67\%$$

The overall result is shown in table 4.5.

Table 5: Summary of the results

Parameters	Numerical values
Machine availability	= 87.67%
Performance efficiency	= 77%
Quality	= 99.6%
Overall equipment effectiveness	= 67%

5. Discussions of Results

Following the values obtained from chapter four of this work, we proceed to make interpretation of achieved computations and other features found in this work.

5.1 Case Study

Frigoglass plastics industries Nigeria Limited, Ughelli, Delta State, offered a conducive environment for the success of this research work. The raw data obtained from the company as well as other useful information prompted productive ideas that yielded enormous output upon which this work pings. The values obtained are meant for justifying the research initiatives. Furthermore, to evaluate the availability of the 750 tons injection molding machines, the mean time between failure (MTBF) and mean time to repair (MTTR) were calculated. The value of the availability was obtained to be 87.67% which indicates a meritorious utilization. In order to assess the machine complete performance quality was calculated and the value obtained was 99.6%. it shows a good percentage of the products yield from the machine.
Moreover, the 77% performance efficiency is a demonstration of satisfactory operation of the machine.
Finally the culmination of the three parameters mention above yielded a 67% overall equipment effectiveness of the machines which in average is useful.

6. Conclusion

It is essential for a company to improve the production rate and quality of products. In doing this good knowledge of availability analysis is essential order to know how to categorize failures and identify the one which limits the machine availability. The overall availability of the 750 ton injection molding machine was determined to be 87.67% and the overall equipment effectiveness was obtained as 67%. Through this knowledge, it becomes obvious that power failures should not be used as measure for machine unavailability. Well analyzed data leads to better utilization of resources, high quality products and employee morale and confidence can be raised to improve productivity.

7. Recommendation

I strongly recommend that Engineers and the operators should be trained on machine performances analysis to be able to identify which areas of operations require improvement. Wrong analysis provide wrong information and could mislead management, This is the basis upon which the initiatives of this work rest.

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