Sensitivity analysis on a variant machine guard compliance productivity model (VMGPEM) for a bottling plant using the OFAT technique

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Abstract. Certainly, the operating errors of a given model can be assuaged by proper selection of its working parameters and distinctly identifying the most critical for optimization. To achieve this objective, sensitivity analysis is introduced to the system to show relevant strengths and avoidable lapses. For this study, the one-factor-at-a-time (OFAT) sensitivity analysis technique is employed to the model to disclose the input parameters in form of guard categories that is most significant in optimizing the machine guard compliance productivity for a particular period. The result of the experiment reflected fixed guards as the most significant guard category by which machine guard compliance productivity for the bottling plant can be optimized.

Keywords: machine guard; critical parameter

1. Introduction

Machine guards are protections against injuries, attached on workshop equipment as safety mechanisms. They shield machine operators’ body from interaction with material particles, noise and harms, which is a huge progress towards achieving the no-accident goal in any work station. As the need to measure operators’ compliance arose in the bottling plant, a variant machine guard productivity evaluation model was designed. This model was to measure the productivity of the operator with respect to machine guard compliance having the start period of the experiment as a root period. The model is designed to have input and output sections. The numbers of functional guards for the categories engaged are carefully observed for their use during production processes and recorded during the investigation span. The model shows how the output to inputs ratio can be used as a determining value. The farther the value for machine guard compliance productivity is away from unity is indicative of a poor performance and the closer it gets the better the performance by the operator in complying to guard usage.

This model helps the operations manager to evaluate the operators on their compliance to guard usages and to quickly spot damaged guard for replacement in other to reduce injury tendencies and keep proper inventory of guard parts. It was observed that machine guard compliance productivity over the selected periods were within the range of 0.60-0.70. This appears not to be completely satisfactory as it is interpreted as 60%-70% guard compliance productivity. This prompted the employment of sensitivity analysis using the one-factor-at-a-time technique to investigate this situation. The one-factor-at-a-time sensitivity analysis also known as the local sensitivity analysis investigates the importance of parameters by altering one parameter after another, while doing this it keeps all other parameters fixed. This increases the comparability of the results. This regularly chosen method is employed by many scientists as it gives room to immediately spot out input parameters that initiated poor performances in a system and by what magnitude and vice-versa. The sixth period was selected for the application of the OFAT technique as it showed the most productive period for machine compliance with a productivity of 0.6794, in other words 67.94% productivity percentage. The OFAT technique was systematically applied on the parameters for the sixth period to identify the most crucial parameter, vary it by certain percentages and note its optimal compliance productivity value. For this study, the OFAT technique worked adequately for optimization of machine guard compliance productivity.
2. Brief literature review

This section will be presenting a brief overview of few works found in literature relating to machine guard usage. Eckhardt in 2001 investigated on the diverse enhancements achieved in the employment of guards in machinery [1]. To reveal the implication of working in systems without guards, the aim of securing the employment of machine guards as well as the benefits, with particular instance drawn from the huge system used to guard a 4-bolt shaft was emphasized. In 2012, Soranno emphasized the importance of machine guarding in production systems [2]. The exposition centered on the need for machine guarding, the concept of design as well as machinery installation. In 2013, Rubinger and Hamilton centered discussion on matters associated with the guarding of machines and aid to assist in the achievement of a safe working relationship with woodworking machines [3]. In 2006, Cordier emphasized on promoting machine guarding usage with report given on the injuries sustained in production centers in relation to rotating parts of machines [4]. Furthermore, Berke in 2008 discussed four general methods in machine guarding: guarding devices, warnings, barrier guards and guarding by location [5]. Barrier guard was emphasized as a necessary requirement in most industrial settings and that its effective usage ensures a separation of the hazards from the operator of the machines. With the introduction of the variant machine guard productivity evaluation model (VMGPEM) this gap was breeched with room for improvements because of unsatisfactory results thus a need to investigate the situation using the OFAT sensitivity analysis technique. A brief overview of sensitivity work in literature follows.

In 2013, Tian said that methods used for sensitivity analysis can be categorized into local and global methods [6]. Local sensitivity analysis is associated with one-factor-at-a-time (OFAT) methods by Navid et al. in 2018 [7]. OFAT technique understudy’s system results with the changes in input parameter values. With respect to this technique, one parametric input value is varied, while the other parametric values remain fixed main values. In 2016, Paleari and Confalonieri affirmed that this method can reoccur for other parameters [8]. OFAT sensitivity analysis techniques tends to establish dependency on parametric values, and relevant in understudying challenges with a few compromising factors. Furthermore, Navid et al. in 2018 conferred that the gross weakness of local sensitivity analysis techniques is that they are inaccurate for nonlinear models [7]. For this investigation OFAT sensitivity technique was proposed to identify crucial parameters.

3. Methods

The current analysis was carried out to investigate the effect on the output for productivity from a Variant Machine Guard Productivity Evaluation Model VMGPEM analysis when its main factors are altered. The VMGPEM analysis in this work was done using the first month of the data collection interval as the base or root period and the results obtained for productivity of machine guard compliance were all less than 70% of the original status value. From table 1 below, the highest compliance percentage was obtained in the sixth month with 67.94% compliance productivity and on the other hand the lowest compliance productivity was observed from the first, eighth and eleventh month having compliance productivity of 65.46% apiece. The sensitivity analysis carried out in this investigation is aimed at studying the guard categories considered for the model makeup and altering their respective percentage compliances by -25%, -20%, -15%, -10%, -5%, 5%, 10%, 15%, 20% and 25% in the VMGPEM that by so doing the category that gives optimal compliance productivity will be identified. With respect to the objective of the study, the VMGPEM analysis for the sixth period was considered separately for sensitivity since it had the highest compliance productivity. Therefore, altering the guard categories for this period will not only display the behavioral response of the machine guard compliance productivity output to changes but will also indicate the category which will yield optimal productivity when increased to a certain acceptable level. In the sensitivity analysis 25% is selected as the peak altering value as a percentage compliance above 100% will occur if it is exceeded with respect to the percentage arithmetic progression of 5% used in this work. Furthermore, in the course of the analysis the percentage compliance of categories in the base period were increased simultaneously by 5%, 10%, 15%, 20% and 25% respectively. The same was also done for the percentage compliance for all the compared periods. The results from this analysis will be graphically represented.
The data used for this work was obtained from a bottling process plant situated in the western region of Nigeria. The data was retrieved from the company’s safety monitoring unit and spanned for a period of 12 months as it was considered to be quite sufficient to getting hold of relevant test results. The data gotten was arranged in sequential months and coded according production process lines. The data was summed up, averaged and tabulated. This information was further transferred to a Variant Machine Guard Productivity Evaluation Model (VMGPEM) appropriately and results of productivity was shown and this was done by retaining the first month as a root period in comparing other months. The basic results were gotten for all compared periods without any alteration. However, for the sake of this test alterations were employed to identify the guard category that will give maximum productivity when improved by a certain percentage.

Based on the data in Table 1: Considering the impact of external forces on oil spills, this paper analyzes the assessment of the effective rescue levels of each rescue point relative to the oil spill batches, and we can calculate the effective rescue degree matrix $P$ of six bases relative to each oil spill batch.

|       | Period 1 | Period 6 | Biased Variation Ratio |
|-------|----------|----------|------------------------|
|       | $\alpha_i$ | $\alpha_i \cdot \Omega_i$ | $\alpha_i \cdot \Omega_i$ | $\alpha_i \cdot \Omega_i$ | $\frac{\alpha_2 \cdot \Omega_1}{\alpha_1 \cdot \Omega_1}$ | $\frac{\alpha_2 \cdot \Omega_2}{\alpha_2 \cdot \Omega_1}$ | $\frac{\alpha_2 \cdot \Omega_2}{\alpha_1 \cdot \Omega_1}$ |
| F     | 487      | 345.77   | 487                    | 0.73                 | 355.51                  | 1                   | 1.028169                     | 1.028169                     |
| I     | 354      | 205.32   | 354                    | 0.62                 | 219.48                  | 1                   | 1.068966                     | 1.068966                     |
| E     | 279      | 220.41   | 279                    | 0.79                 | 220.41                  | 1                   | 1                           | 1                           |
| L     | 103      | 65.92    | 103                    | 0.73                 | 75.19                   | 1                   | 1.140625                     | 1.140625                     |
| T     | 208      | 147.68   | 208                    | 0.73                 | 151.84                  | 1                   | 1.028169                     | 1.028169                     |
|       |          |          |                        |                      |                        |                     | $\Delta = 1.037895$          |                              |
| TOTAL | 985.1    | 1022.43  |                        |                      |                        |                     |                              |                              |

Original Status

|       |       |       |       |       |       |       |
|-------|-------|-------|-------|-------|-------|-------|
| F     | 490   | 1     | 490   | 1     | 490   | 1     | 1     | 1     |
| I     | 420   | 1     | 420   | 1     | 420   | 1     | 1     | 1     |
| E     | 280   | 1     | 280   | 1     | 280   | 1     | 1     | 1     |
| L     | 105   | 1     | 105   | 1     | 105   | 1     | 1     | 1     |
| T     | 210   | 1     | 210   | 1     | 210   | 1     | 1     | 1     |
| TOTAL | 1505  |       | 1505  |       |       |       | | |

Productivity for period 1 = 0.654551
Productivity for period 6 = 0.679355

Change In Guard Compliance productivity = 1.037895
4. Results

![Graph showing the effect of reductions and increments of guard categories on the machine guard compliance productivity.](image)

Figure 1: The effect of reductions and increments of guard categories on the machine guard compliance productivity

Results from the VMGPEM analysis shows that period six is the period with maximal guard compliance productivity. The sensitivity analysis was therefore carried out on the individual guard categories in period 6 to determine the guard category with the potential of further increasing the period’s compliance productivity and to what optimal percentage increase the guard category can be adjusted to. The guard categories considered here are; Fixed guards (F), E-Stop guards (E), Lagging guards (L), Trip devices (T) and Interlocking guards (I). Figure 1 shows the effect of reductions and increments of guard categories on the machine guard compliance productivity. The maximum productivity of 73.84% was obtained when fixed guards were upped by 25%. While the guard that had less impact on the productivity was lagging guard, having 69.18% after 25% increment. This implies that a 25% increase in the percentage compliance of fixed guards will optimize the machine guard compliance during the sixth period to 73.84%.

5. Conclusion

The sensitivity analysis carried out on the variant machine guard productivity evaluation model is imminent to figure out lapses to be adequately tackled for a profitable work experience in the bottling plant. This study being a maiden work on optimizing machine guard compliance productivity breached the gap successfully for the bottling plant used for the experiment. The OFAT technique employed for this work provides a clear indication of the guard category that needs to be given attention to by machine operators with respect to compliance to its engagement during processing periods. Advanced work will be advised to be carried out by the safety and maintenance department using other adoptable methods to improve results from the VMGPEM by understudying how improvement on the number of functional machine guards across the guard categories will affect the machine guard compliance productivity values.
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