An alternate productivity evaluation practice to depict machine guarding performance in a process plant

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Abstract. Varying from the notion that the significant expenditure channeled on machine guarding has little or no benefit, this paper through an innovated model, argues that the machine guarding productivity could be evaluated for progress in a bottling production company. This paper contributes to the literature on machine guarding by developing a novel variant machine guarding productivity evaluation model which was validated with dataset from a process plant in Nigeria. Well descriptive results from the model shows that when period 5 is compared with period 1, the model showed an increase in % compliance for trip guards, fixed guards and e-stop guards by 2.82%, 1.41% and 2.53% respectively, while the number of functional guards remained unchanged across all guard categories. As a result of the increment in % compliance for the afore mentioned guard categories, there was an increment in machine guard compliance output for the affected guard types, thus a rise in total machine guard compliance output from 985.1 to 993.08. The machine guard productivity for periods one and five showed a 34.54% and 34.01% decrease for the respective periods from the original status. It also reveals a 0.81% change in guard compliance productivity from period 1 to period 5. The model showed the efficiency of the framework in evaluating operator’s productivity performance as a useful source of information for operations managers to trace and adjust quantifiable productivity targets of the machine compliance scheme. Keywords: machine guard; compliance

1. Introduction

Scholars have increasingly directed interest to a kind of safety process called the machine (equipment) safety [1-3]. Their investigations have revealed that machine safety is largely associated with other safety categories in industry, such as the human safety, occupational safety [4], environmental safety, and the degree of attention paid to these safety categories will determine the level of safety in the industrial enterprise [5]. While the safety literature has made substantial advancement in bringing out interesting ideas concerning the dynamics of safety and the intricate nature of machine safety, numerous principal questions about machine safety stands unanswered [6-7]. In particular, despite the fact that previous research has strongly emphasized the significance of high productivity in the sustenance of machine safety guards, researchers have, in general restricted their interest to the design aspect: an area of research that is believed to lessen the hazards provided by the machine through continuous weight reductions in new designs, enhancement in the overall cost of the equipment and enhancement in equipment noise production and other machine safety guard quality enhancement issues.

There are a number of probable problems with this method of machine safety guarding. The collective emphasis on design has robbed the safety community of the immense benefits of evaluating both the operator and the workplace. The operations manager is unclear about how to achieve optimum results from the guarding influences and compliance of the operator as there is absolute confusion on what to get done in terms of productivity since no concrete measurements are being done concerning inputs and the responses of the machine safety to guarding system. Secondly, a huge challenge exists in properly evaluating the value of investment on machine guards and reports are difficult to create and this in turn leads to long period of waiting for requests for machine guards related issues by operator due to tactical delay by management not to expend on the activity. The suggestion is that a radical pursuit of productivity measurement programs for the machine safety operator directed at the employee’s compliance to the use of machine safety guarding from the productivity evaluation perspective may cause a turnaround of the
unattractive situation. In this research, these principal challenges are resolved by drawing inspiration from the theory of productivity to develop a machine guarding compliance model based on the ability and willingness of the operator to comply with the judicious utilization of materials via surrogate measures of incorporating the functionality of guards and this will clearly help create laid out procedure for evaluating the operators productivity and the operator’s productivity is made and the operator is aware of his/her periodic performance. Little dependence on the operator is made for certain information on machine guards and request by management or third parties could easily be satisfied by the operations/safety manager instead of putting burden on the operator for information.

The model is principally segregated into inputs and outputs. The numbers of functional guards of the diverse categories are carefully observed for their activations in use by the operator during any production activity through a physical count of the “on” and “off” states of machine guarding usage by the operator over the study period. The responses are then taken as the amount of guards in the right state of usage, indicating the output of the system. The model reveals how the ratio of output to inputs could be used as a parameter for the judicious resource usage in comparison with unity. A value less than unity is not satisfactory indicating poor performance while unity indicates acceptable performance and a value greater than unity shows outstanding performance that is desirous to be sustained and improved upon.

2. Brief review of literature

In 2009, Parker et al. published the report of an investigation that centered in interventions for safety and the primary attention of the researchers were directed to how the fabrication industries could be assisted with respect to safety programs [8]. The current investigators noted with interest that this report adds knowledge to the domain of interest in this investigation from the perspective of inputs for the manufacturing system, to enhance the machine guarding performance appraisal. In 2012, Peabody in their contribution that broadly centered on the movable as well as fixed guards (i.e. Categories as well as B), considered the protection of operators from any kind of hazards both in the whole span of life of the machine as well as for the daily and short-term interactions with the machines [9]. The interest of Rubinger and Hamilton in 2013 was a machine guarding in wood product manufacturing systems. A safety-conscious mindset was perceived as the gateway to avoiding accidents [10]. The review of this investigative document is relevant to the current researchers’ study focus on evaluating the performance (productivity) of machine guard operators in a manufacturing system. Foo and Wong in 2015 appraised the risk in a manufacturing organization devoted to cutting tool usage [4]. In 2017, Kyslinger produced a novel roof bolting equipment for underground mining wherein guarding was apprehended to restrict the operator’s reach area to those outside the possible accidental contact with a drill [11]. This research work is relevant to the current study of productivity evaluations of the machine guarding operator wherein the proper consideration of the guarding would lessen the risk of accident by the operator. A study was carried out in 2016 by Wong and Lee studying the intention of employees to comply with safety regulations among manifold ethnic classes of people [12]. In 2016 Hu and Bertuleit further focused on the integration of the theory of technological acceptance in the workplace [13]. Drawing insights from the prior literature concerning machine guarding, it is ascertained that a huge volume of studies has been contributed on machine guarding fundamentals and the use of basic compliance or non-compliance verifications of the operators at the workstation and not on established performance metrics of productivity indices. The bridging of this huge gap is an effort made in this research as the study focuses on the quantification of productivity of the machine guarding operator in terms of utilization of the scarce resources provided to the operator from the perspective of output to input vis-à-vis the machine guarding function.

3 Methods

The main objective of this innovative investigation is to ascertain the machine guard efficiency in the bottling plant used as a case study; to identify lags in the company’s safety status as well as guard maintenance routines for adequate attention, to see what periods had the optimal and minimal functional
number of machine guards and also the periods with greater operator’s compliance to machine guard usage. To get this accurately done the Variant Machine Guard Productivity Evaluation Model (VMGPEM) was employed to achieve the desired purpose. This is gotten by the evaluation of different types of machine guards used on equipment along all production process lines in the plant and further the efficiency values are obtained. Literatures were analyzed to point out gaps and inefficiencies in the measurement of machine guard compliancy. The case outfit is a bottling plant located in western region of Nigeria. The firm comprises of four production process lines with each having eight processing machines for the entire production. Data for the machine guards were obtained from the maintenance inspection unit for a period of 12 months. From the data it was observed that equipment in each process line comprised of five different types of guards; fixed guards, Interlock guards, trip guards, lagging guards and E-stop guards. These guards and its compliance by machine operators are major determinants in measuring machine guard compliance productivity using the innovated VMGPEM. The relevant data after taken were properly collated. The VMGPEM follows a systematic tabulated procedure to give desired output.

An overview of relevant terms and model construct is as follows:

Table 1 Variant machine guard productivity evaluation model (VMGPEM)

| Current Status | Period 1 | Period 2 | Biased Variation Ratio |
|----------------|---------|---------|------------------------|
|                | α_i  | θ_i  | α_iθ_i | α_i  | θ_i  | α_iθ_i | α_iθ_i/α_iθ_1 | α_iθ_i/α_iθ_1 |
| Original Status | F | I | E | L | T |

\[ \Delta = \text{TOTAL} \]

In VMGPEM, a base period is taken and used to compare outputs for other periods. Table 1 reflects a part of the model where:

- Period 1: is the selected base period used to compare the other periods. It is also the first month from the data.
- Period 2: indicates the next period being compared with period 1. F: symbolizes fixed guards I: signifies interlock guards
- E: represents e-stop guards L: stand for lagging guards
- T: is for trip guards
- α_i: denotes number of functioning guards in a period
- θ_i: is the % compliance in the usage of machine guards
- α_iθ_i: represents guard compliance output
- α_iθ_i/α_iθ_1: is the weighted guard compliance output ratio having % usage compliance constant to reflect actual changes in number of functional guards
- α_iθ_i/α_iθ_1: signifies weighted guard compliance output ratio with the number of functional guards constant to reveal the actual variation in % compliance
• $\alpha_2\theta_2/\alpha_1\theta_1$: is for guard compliance ratio $\Delta$: change in compliance to machine guard Current Status: indicates the present number of functional machine guards for each period. Original Status: this shows the actual number of guards that are meant to be functional for each.

4. Result

Table 2 VMGPEM analysis of period 1 and period 5

|                  | Period 1 | Period 5 | Biased Variation Ratio |
|------------------|----------|----------|------------------------|
| Current Status   | $\alpha_i\theta_i$ | $\alpha_i\theta_i$ | $\alpha_i\theta_i$ | $\alpha_2\theta_1/\alpha_1\theta_1$ | $\alpha_2\theta_2/\alpha_1\theta_1$ | $\alpha_2\theta_2/\alpha_1\theta_1$ |
| F                | 487      | 0.71     | 345.77                 | 487       | 0.72     | 350.64   | 1         | 1.014084507 | 1.014084507 |
| I                | 354      | 0.58     | 205.32                 | 354       | 0.57     | 201.78   | 1         | 0.982758621 | 0.982758621 |
| E                | 279      | 0.79     | 220.41                 | 279       | 0.81     | 225.99   | 1         | 1.025316456 | 1.025316456 |
| L                | 103      | 0.64     | 65.92                  | 103       | 0.61     | 62.83    | 1         | 0.953125    | 0.953125    |
| T                | 208      | 0.71     | 147.68                 | 208       | 0.73     | 151.84   | 1         | 1.028169014 | 1.028169014 |

TOTAL          | 985.1    | 993.08   |

Original Status

|                  | $\alpha_i\theta_i$ | $\alpha_i\theta_i$ | $\alpha_i\theta_i$ | $\alpha_2\theta_1/\alpha_1\theta_1$ | $\alpha_2\theta_2/\alpha_1\theta_1$ | $\alpha_2\theta_2/\alpha_1\theta_1$ |
| F                | 490      | 1        | 490                   | 490       | 1        | 490      | 1         | 1         |
| I                | 420      | 1        | 420                   | 420       | 1        | 420      | 1         | 1         |
| E                | 280      | 1        | 280                   | 280       | 1        | 280      | 1         | 1         |
| L                | 105      | 1        | 105                   | 105       | 1        | 105      | 1         | 1         |
| T                | 210      | 1        | 210                   | 210       | 1        | 210      | 1         | 1         |

TOTAL          | 1505     | 1505     |

Productivity for period 1 = 0.654551
Productivity for period 5 = 0.65985382

Change In Guard Compliance productivity = 1.0081007

Table 2 above shows a layout of the model comparing period-5 with period-1. The model showed that there was an increase in % compliance for fixed guards, e-stop guards and trip guards by 1.41%, 2.53% and 2.82% respectively, while the number of functional guards remained unchanged across all guard categories. Due to the increase in % compliance for certain guards there was an increment in machine guard compliance output for the affected guard types, hence an increase in total machine guard compliance output from 985.1 to 993.08. Productivity being the ratio of the current status value for total machine guard compliance of periods to the total the original status value of total machine guard compliance, we have that the machine guard productivity for period one and two is 0.6546 and 0.6599 respectively. This can be interpreted as a 34.54% and 34.01% decrease in productivity for the respective periods from the original status. It also reveals a 0.81% change in guard compliance productivity from period 1 to period 5. This obviously speaks to the point that an increased percentage compliance to guard usages by operators will also increase the machine guard productivity.
5 Conclusion

The existent literature on machine guarding so far has considered the design of machine guards to attain the required safety limit standards by supervisory bodies, but issues concerning the performance of operators monitoring the machine workplaces is almost absent. In this contribution, this particular challenge of productivity quantification for the machine guarding operator has been overcome through the employment of the competent productivity quotients. Visualizing parameters as inputs and other as outputs, while the quotients are carefully analyzed. Data from a soft bottling processing organization was considered to establish the competence of the proposed methodology. An advanced approached in this research is largely appropriate to solve and attain productivity indices for process industries such as those in the drinks manufacturing system. The results demonstrate that the productivity appraisal approach is competent in diagnosing the productivity performance in terms of being poor or good and causal factors may be further investigated in subsequent studies as well as other human factors such as fatigue could be analyzed to further understand the dissimilarities in the productivity indices.

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References

[1] GOOMAS D T, YEOW P H P. IT-assisted equipment safety checks system to improve compliance: A case study at a distribution center. Safety Science, 2013, 60: 77-86.
[2] PALAZZI E, CURRÒ F, FABIANO B. A critical approach to safety equipment and emergency time evaluation based on actual information from the Bhopal gas tragedy. Process Safety and Environmental Protection, 2015, 97: 37-48.
[3] VAHDATIKHAKI F, LANGARI S M, TAHER A, EL-AMMARI K, HAMMAD A. Enhancing coordination and safety of earthwork equipment operations using multi-agent system. Automation in Construction, 2017, 81: 267-285.
[4] FOO S H, WONG K Y. Occupational safety and health improvement in a cutting tools manufacturing company. Proceedings of the 26th International Business Information Management Association Conference: Innovation Management and Sustainable Economic Competitive Advantage: From Regional Development to Global, 2015: 446-462.
[5] QUARTEY S H. Examining employees’ safety behaviors: an industry-level investigation from Ghana. Personnel Review, 2017, 46(8): 1915-1930.
[6] MOHAMED S, CHINDA T. System dynamics modelling of construction safety culture. Engineering, Construction and Architectural Management, 2011, 18(3): 266-281.
[7] RIPAMONTI S C, SCARATTI G. Safety learning, organizational contradictions and the dynamics of safety practice. Journal of Workplace Learning, 2015, 27(7): 530-560.
[8] PARKER D L, YAMIN S C, BROSSEAU L M, XI M, GORDON R, MOS I G, STANLEY R. National machine guarding program: Part 1, Machine safe-guarding practices in small metal fabrication businesses. American Journal of Industrial Medicine, 2015, 58: 1174-1183.
[9] PEABODY J. The dos and don’ts of fixed and moveable machine guards. Today, 2012, 5(1): 39.
[10] RUBINGER J, HAMILTON J. Machine guard guidelines. Wood Products, 2013, 118(2): 18.
[11] KYSLINGER B. Development of a six drill head roof bolting machine," SME Annual Conference and Expo 2017: Creating Value in a Cyclical Environment, 2017, 196-200.
[12] WONG D B, & LEE S G. Modeling the predictors of intention in workplace safety compliance of a multi-ethnic workforce. Safety Science, 2016, 88: 155-165.
[13] HU X, GRIFFIN M A, BERTULEIT M. Modeling antecedents of safety compliance: Incorporating theory from the technological acceptance model. Safety Science, 2016, 87: 292-298.