International Journal of Production Management and Engineering

https://doi.org/10.4995/ijpme.2019.10911
Received: 2019-01-22 Accepted: 2019-07-29

Developing a Novel Based Productivity Model by Investigating Potential Bounds of Production plant

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Abstract: Productivity level is based on reliability impression which is the primary aspect of the automatic assembly line for continuous production. Productivity forecasting is a professional tool helping to enhance production system and attain the client petition by using precise model. Due to mechanisms complexity of assembly lines, analysis of failure factors contributes a significant role for investigating potential bounds that require analytical approach to compare the current and proposed model of productivity effects. The issues related to the production losses need additional space for improvement of the productivity model which may not present a close comparison between the current and proposed productivity rate. The main purpose of this paper is to develop a novel based productivity model that will predict alternatives for the availability of assembly line workspaces pertain to an automobile tire manufacturing plant. For investigating the potential bounds of the productivity losses, DMAIC and PACE techniques were used. It was revealed that the novel productivity model yielded better results of 3.358% errors showing its accuracy as compared to real productivity level at different workspaces.

Key words: Manufacturing system, automatic assembly lines, tire productivity, DMAIC.

1. Introduction

Productivity is a crucial indicator to point out the performance in a manufacturing unit. There are some approaches to precise productivity(Gharfalkar, Ali, & Hillier, 2018). It can be articulated using different insights, prototypical variables, speculative outline and financing procedures(Edgar & Pistikopoulos, 2018). From the outline of the operations research, there are three different viewpoints about productivity extent which are cost-effective, engineering, and manufacturing(Singh, Singh, & Sharma, 2018). A High rate of production means the involvement of extra manpower which yields high productivity. According to cost-effective productivity perception productivity is the ratio of outputs to the inputs as expressed in relation 1 (S. K. Gupta, Gupta, & Dhamija, 2019). Figure 1 illustrates the characterization of productivity in which the input resources are transformed into desired outputs.

$$\text{Productivity} = \frac{\text{Goods produced}}{\text{Input used}} \quad (1)$$

Manufacturing and consumption are the two major concerns of the productivity.

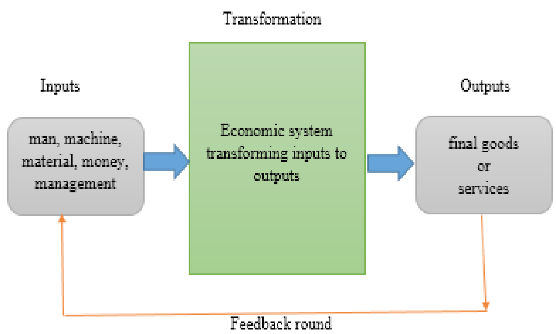

Figure 1. Cost-effective system value adds by transforming inputs to outputs.

To cite this article: Hussain, Z. (2019). Developing a Novel Based Productivity Model by Investigating Potential Bounds of Production plant. *International Journal of Production Management and Engineering, 7*(2), 151-159. https://doi.org/10.4995/ijpme.2019.10911

During the production process input and output are transformed however consumption is coverging on the practice of processing plants and organization (Giovannetti & Piga, 2017). However, productivity in the cost-effective aspect is centering on variables like quality, quantity and cost of the final good produced (Nawanir, Fernando, & Teong, 2018). The engineering perspective of productivity requires more impost due to the involvement of industrial equipment and technological processes (Fettermann, Cavalcante, Almeida, & Tortorella, 2018). Productivity in this case, is based on the best techniques to the extent of the overall equipment effectiveness. Overall equipment effectiveness (OEE) is extensively recognized and consistently used as a quantifying tool for measuring the production capacity of single equipment in industries (Hussain, 2018). Owing to advancements in the technological process, production systems and developments are converting into more complex and automated assimilation which seriously concerned with equipment effectiveness followed by innumerable practices of human control (Dresch, Veit, Lima, Lacerda, & Collatto, 2019). The analysis and modeling of productivity for such complex systems are becoming a competitive contest for concerned engineers as well as researchers in academic spheres (Yan et al., 2018). Expression 2 is considered to present OEE as a mathematical model on the basis of Availability level (A), Performance (P) and Quality level (Q):

$$OEE=(A)\times(P)\times(Q) \tag{2}$$

According to OEE model, the availability level (A) is crucial for productivity which reflects the diminishing of production time while performance (P) reflects the actual production time delays and the quality level (Q) reflects the satisfactory quality values (Yazdi, Azizi, & Hashemipour, 2019). The manufacturing viewpoint of productivity emphases and concentrating on the level of production of a specific workspace within the industry which follows the constraints of quantity requirements and the time of producing goods (Xu, 2017). The study of the productivity model of different workspaces is imperative in modern assembly lines as it enables the estimation of a certain manufacturing system (Morales Méndez & Rodríguez, 2017). However modern industries use fully automated production lines because of the tough industrial competition, rapid demands and complication in products characteristics (Bauerdick, Helfert, Petruschke, Sossenheimer, & Abele, 2018). The need of applied research about modeling for such complex automated processing lines and workspaces is extremely imperative to be revealed (Hussain, 2019). Regarding the role of the productivity model in processing units, expression 3 is normally used for measuring productivity in automated production lines.

$$\text{Productivity (Q)} = \frac{\text{Parts produced (n)}}{\text{time for production (t)}} \tag{3}$$

This model determines the level of productivity for the amount of the goods produced and the corresponding time consumed to produce those goods in a specific workspace and processing assembly line (Manitz, 2008). Besides establishing productively modeling, an ordinary level of reliability has already been industrialized. Considering the operating time of the product (t_{op}), auxiliary time for loading a piece in machine area (t_{ax}) with number of working spaces (x), mean time to repair (t_{mr}), rate of the failure of a workspace (λ_w), rate of the failure of transportation ($\lambda_{(t)}$) and ($\lambda_{(cs)}$) as rate of the failure of transportation system of the whole unit and finally ($\lambda_{(d)}$) as the failure frequency of defective parts then, the model takes in account a sequential linear part as shown in Equation 4.

$$\text{Productivity } (Q_{AR}) = \frac{1}{(t_{op}/x)+t_{ax}} \times \frac{1}{1+t_{mr}\{x(\lambda_w)+\lambda_{(t)}+\lambda_{(cs)}+\lambda_{(d)}\}} \tag{4}$$

The productivity model under study using system availability seems not to be precise to present authentic productivity rate due to limitations of some of the productivity constraints. Therefore, those potential bounds are necessary to be examined before to discover a true productivity model.

2. Methodology

To explore an accurate productivity model, the required potential bounds are investigated using DMAIC approach which is a famous data-driven quality strategy for improving the manufacturing processes and PACE Matrix technique used for prioritizing various production task. DMAIC approach addresses on the quality issues for refining progressions which is fundamental fragment of the Six Sigma Quality Initiative (Neha Gupta, 2013). DMAIC approach establishes five consistent levels including Define, Measure, Analyze, Improve, and

Control. Each level in the process is essential to achieve the optimum expected outcomes ("Study and Analysis the Wastage Reduction of Fluorescent Powder in CFL 23 W in Philips Pvt Ltd Mohali, Using Six Sigma Methodology," 2016). On the other hand, PACE Prioritization Matrix which was formed by Karen Martin Group, is a LEAN engineering tool established to explore the productivity parameters for increasing the production efficiency (Sin et al., 2014). To improve the productivity model using system availability using Lean as well as Sigma techniques, PACE Matrix is introduced during the improvement stage of DMAIC approach to identify the required factors. The DMAIC methodology is based on defining the issues related to the enhancement of the production parameters for presenting an effective productivity model. This methodology is shown in Figure 2 in the form of a flowchart.

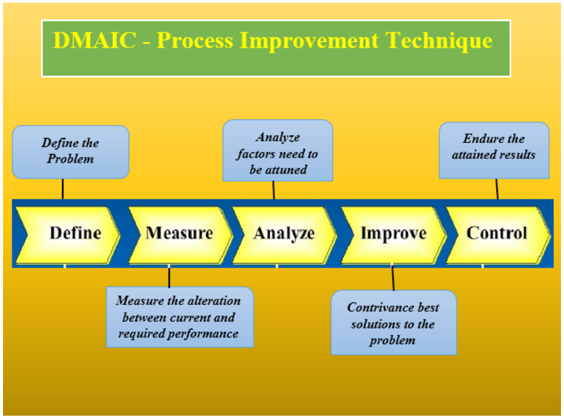

Figure 2. DMAIC approach flowchart for exploring productivity parameters

Define: To state and outline the most negative aspect of the model, the productivity model in machine-controlled and production line with the accessibility of productivity is needed. However, based on the two productivity equations discussed above, it should be clear enough to point out the product comparison.

Measure: For measuring the difference and analyzing the comparison between the current and desired productivity parameters related to actual and reliability approaches, both the productivity equations are used through operational order. After applying the equations (6) and (7) the computation will show the nonconformity results of the productivity model by comparing the current system reliability and actual productivity performance.

Analyze: This step helps to determine the gap between the current and goal performance through contributing opportunity to analyze the difference between the model of productivity and availability for which loss diagram has been considered. By the implementation of loss diagram the factors necessary for the productivity model which may be left ignored are re-analyzed for process improvement (V. Gupta, Jain, Meena, & Dangayach, 2018).

Improve: For improving the effectiveness of productivity model parameters, PACE Matrix technique is implemented to determine the significance of critical parameters (Zhang et al., 2018). The output is categorized using different spaces of PACE criteria. Priority (highest anticipated value of productivity parameters), Action (slightly lower strength with relatively restrained influence of productivity parameters), Consider (Next to P and A implementation, reviewing the process to discover the difficulties occurred during consideration of the model parameters with great influence) and Eliminate (Those factors which do not create difficulties during model formulation).

Control: The control stage keeps the potential parameter of the productivity model from the development level and settles the required potential bounds for further improvement. Present research work has been performed in United rubber industries dealing with the production of automobile tire and tube. All the necessary parameters for developing productivity model, different failures and productivity rates along with production losses were considered in the tire curing assembly hall.

3. Results and Discussion

Data Assortment: For data analysis, three different arrangements of data sets were considered. The first set is the real data consisting of total working shifts, assembly time and tire produced. For this purpose, the data of two months (March and April 2018 with 60 working shifts) has been collected. During this period, total production of tire grade 205/55, R14 W16 was recorded as 7909 with 18000 minutes as production time. Figure 3 presents the production of tires in 60 working shifts for the specified period. The next two data sets are related to technical and reliability concerns, however, the applied data to methodology stated above for determination of research's results are described in tables 1 to 4. Table 3 data values shows the output of tire produced in tire curing assembly hall. The result with DMAIC approach are discussed below.

Define: With accordance to equation (1) productivity is the ratio of goods produced to the input used which follows that as per industrial constraints, productivity may likely be greater than methodological restrictions that is quantity of the goods and producing time, however, the real productivity is based on equation (3). Implementing the reliability concept, the basic equation of productivity has been improved and presented in equation (4).

Measure: Matching both the equations (3) and (4), the real productivity is based on set of additional methodical data applied on above equations for distinguishing the correctness of productivity model with the actual productivity. The detail of this necessary data is revealed in Tables 1–4. Total production time (t, min) as expressed in Table 3 is computed as follows:

$$\text{Production time}\,(t) = t_{op} + t_{ax} = 25\,\text{min} + 0.4\,\text{min} = 25.4\,\text{min} \quad (5)$$

After setting the production time which is equal to the auxiliary time for loading a piece in the machine area, the actual productivity is determined through equation (3) while the findings are presented in Table 3. Finally, the changeover of data presented in Tables 1 and 2 into equation (4) the required productivity model in average is presented. Figure 4 shows the comparison of both fallouts of the actual and model productivity as per findings of the Table 4.

Analyze: Figure 4 reveals that the productivity model results through sole reliability are much progressive as compare to real productivity. Subsequently, the main purpose of the model of productivity in the tire curing assembly unit is to predict the productivity rate with specific and accurate results, therefore the model understudy needs to be enhanced. Further analysis is based on failure rate at different stages which are listed down and their values are calculated for the determination of productivity losses in tire curing assembly hall using the following additional concerns.

Potential Productivity (P_p): The difference between the definite and most effective (optimal) productivity close. It is considered as unique productivity losses due to the lack of idle time and may be determined using the following expression.

$$Pp = \frac{1}{(t_{op}/x)} \quad (6)$$

Table 1. Data description of tire curing assembly line.

Description	Data values
Tire curing time (machine output), t_{op} (min)	25
Auxiliary time for loading a piece in machine area, t_{ax} (min)	0.4
Number of working spaces (x)	40
Adjustment factor recommended for machine output time for bottleneck parameter of workspace (f_{ad})	1.30

Table 2. Data description of reliability listing for tire curing assembly line.

Description	Workspace (x)	Failure frequency/minute (λ_{oa})
Workspaces failure frequency (x, λ_{oa})	1-4	0.0025
	5-8	0.0150
	9-12	0.010
	13-16	0.0047
	17-20	0.0080
	21-24	0.0020
	25-28	0.0030
	29-32	0.0080
	33-36	0.0090
	37-40	0.0080
Failure frequency of all workspaces $\sum_{i=1}^{40} \lambda_{oa}$		0.0702
Average failure frequency of all workspaces		0.00702
Rate of failure of transportation system of whole unit ($\lambda_{(cs)}$)		0.0009
Rate of failure of transportation system ($\lambda_{(t)}$)		0.0004
Failure rate of defective parts produced ($\lambda_{(d)}$)		0.7445
Mean time to repair (m_{tr}),		1 minute

Recurring Productivity (*Pr*): This type of productivity presents the hidden losses of processing time without taking in account the downtime of the machine, however, in actual practice routine based machinery breakdowns and maintenance activities are the part of the normal production system. It is also noticeable that during normal production flow if a certain workspace starts malfunctioning due to any sort of mechanism failure then the whole assembly line is affected resulting in production time delay issues. Recurring Productivity is determined by using the following expression.

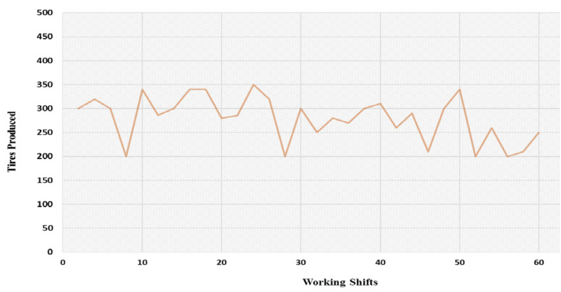

Figure 3. Production of tires against available working shifts in tire curing assembly hall.

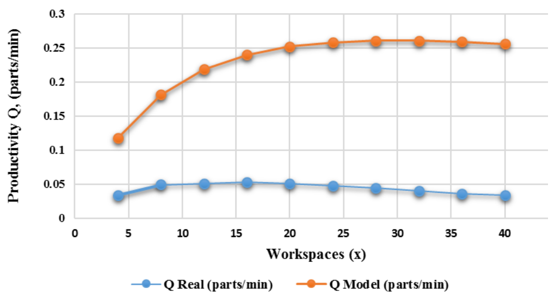

Figure 4. Graphical comparison of real and model productivity.

$$\Pr = \frac{1}{(t_{op}/x) + t_{ax}} \quad (7)$$

Bottleneck bound Productivity (*Pb*): It concentrates on the unfavorable circumstances which mostly exist at assembly line and lead to create other significant economic losses. Therefore, the entire production process may be carefully examined to identify a bottleneck for minimizing its influence.

Taking in account the adjustment factor recommended for machine output time for bottleneck parameter of the workspace (f_{ad}), It may be determined as follows.

$$Pb = \frac{1}{(t_{op}/x) + t_{ax} + fd} \quad (8)$$

Workspace failure level Productivity (*Pw*): It concerns with reliability aspect of the workspaces related machines, taking into account the meantime to repair in case a breakdown occurs. These losses associated with this bound are computed as follows.

$$Pw = \frac{1}{(t_{op}/x) + t_{ax} + fd} \times \frac{1}{1 + m_{tr}\left(\sum_{i=1}^{40} \lambda_{(oa)}\right)} \quad (9)$$

Transportation system failure level Productivity (*Pt*): Expression (10) is used to determine the transportation system failure level productivity. Due to different levels of reliability of each workspaces machines, the failures regarding transportation have to be determined to present a true picture of real productivity.

$$Pt = \frac{1}{(t_{op}/x) + t_{ax} + fd} \times \frac{1}{1 + m_{tr}\left(\sum_{i=1}^{40} \lambda_{(oa)} + \lambda_{t}\right)} \quad (10)$$

Productivity of transportation system failure of whole unit (P_{tw}): *In case* that the entire existing production assembly hall start malfunctioning then, the productivity effect of transportation structure can vary across other industrial sections. Hence, the expression (11) is utilized in such circumstances.

Table 3. Detail of actual productivity for tire curing assembly line.

workspaces (*x*)	4	8	12	16	20	24	28	32	36	40
Total parts produced (*n*)	0.8636	1.244	1.295	1.346	1.295	1.206	1.117	1.016	0.9144	0.8636
Production Time (*t*, min)	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4
Productivity (*Q*, parts/min)	0.034	0.049	0.051	0.053	0.051	0.047	0.044	0.040	0.036	0.034

Table 4. Contrast of productivity model with actual productivity for tire curing assembly line.

workspaces (*x*)	4	8	12	16	20	24	28	32	36	40
Q_{AC}, (parts/min)	0.034	0.049	0.051	0.053	0.051	0.047	0.044	0.040	0.036	0.034
Q_{Mod}, (parts/min)	0.117	0.181	0.218	0.239	0.252	0.258	0.260	0.260	0.258	0.256

$$P_{tw} = \frac{1}{(t_{op}/x)+t_{ax}+fd} \times \frac{1}{1+m_{tr}\left(\sum_{i=1}^{40}\lambda_{(oa)}+\lambda_t+\lambda_{cs}\right)} \quad (11)$$

Defective parts Productivity (*Pd*): Production defects explain defective goods produced through normal production. This happen in almost every sort of manufacturing unit that diminishes the rate of real productivity. It comprises argued fragments followed by those parts which may be reworked and considered as product quality forfeiture and may be determined using expression (12).

$$Pd = \frac{1}{(t_{op}/x)+t_{ax}+fd} \times \frac{1}{1+m_{tr}\left(\sum_{i=1}^{40}\lambda_{(oa)}+\lambda_t+\lambda_{cs}+\lambda_d\right)} \quad (12)$$

Actual or Unique Productivity (*Pac*): It is calculated using expression (13) after considering all the associated productivity losses due to issues concerned with management planning and scheduling that seriously affect the production schedules.

$$\text{Actual Productivity } (P_{ac}) = \frac{\text{total parts produced (n)}}{\text{Production time (t)}} \quad (13)$$

Productivity Comparison: To compare the real productivity in tire curing assembly line with productivity model, the percentage error based strategy is conducted using the expression (14).

$$Error(\%) = \frac{P_d - P_{ac}}{P_{ac}} \times 100 \quad (14)$$

The main purpose of comparison of both the productivities is to prove that the productivity model understudy would yield better and precise results likely to be (< 10%) errors when compared to the real productivity level. Obviously the model productivity rate for different workspace failure levels showed a percentage error of 3.358%. Henceforth it is confirmed and endorsed that the model of productivity level presents the maximum truthful fallouts that satisfy the criteria of (< 10%). For productivity bound's improvement, the productivity losses are presented through productivity losses diagram developed on the basis of productivity equations (09-14) and shown in Figure 5 while the corresponding fallouts are presented in Table 5.

The productivity losses parameter has been demonstrated in mathematical computation form in which L1 represents the productivity losses associated with auxiliary time showing 0.624 tires/min and this is the factor that has the higher impact of losses of the productivity in the final assembly. L2 is concerned with the bottleneck machining time and gives 0.150 tires/min, L3 is the loss of 0.054 tires/min owing to the workspace failure frequency, L4 is the influence of loss related to the controlling system and contributes 0.000647 tires/min, L5 is the lowermost contributor of the losses due to failure of the transportation system of the whole unit, L6 is 0.315555 tires/min that is the second uppermost of productivity losses of caused by various defects in raw material and defective parts produced and preceding is L7 which is due to the unexpected factor like power failure and contributes 0.014753 tires/min.

Improve: After conducting the analysis, the results highlighted various productivity-related issues that could be improved based on the group discussion held with the plant management team of United rubber industries. The group comprised of individuals involved in actual productivity of tire curing assembly line and the productivity model researchers.

A maintainable improvement process is carefully selected using PACE prioritization matrix as shown in Figure 6 which is the outcome of the group discussion. The defective tire parameter is desired to be enhanced owing to its higher influence on productivity losses and for the reason that it is easy to improve as compared to the others productivity losses.

Control: Control is the concluding juncture to establish the measures and examines identified potential productivity bounds for improvement. These bounds are suggested to be implemented in a prospect growth as a vigorous productivity models related to assembly lines.

Table 5. Dissimilarity of productivity model with real one for tire curing assembly line.

Productivity losses due to t_{ax}	L_1	P_p - P_r	1.600-0.975	0.624 parts/min
Losses due bottleneck bound Productivity	L_2	P_r - P_b	0.975-0.824	0.150 parts/min
Workspace failure level Productivity losses	L_3	P_b -P_w	0.824-0.770	0.054 parts/min
Transportation system failure level Productivity losses	L_4	P_w -P_t	0.770-0.769	0.000647 parts/min
Losses due to failure of transportation system of whole unit	L_5	P_t- P_{tw}	0.769-0.769	0.000288 parts/min
Defective parts Productivity	L_6	P_{tw} -P_d	0.769-0.454	0.315555 parts/min
Actual or Unique Productivity	L_7	P_d -P_{ac}	0.454-0.439	0.014753 parts/min

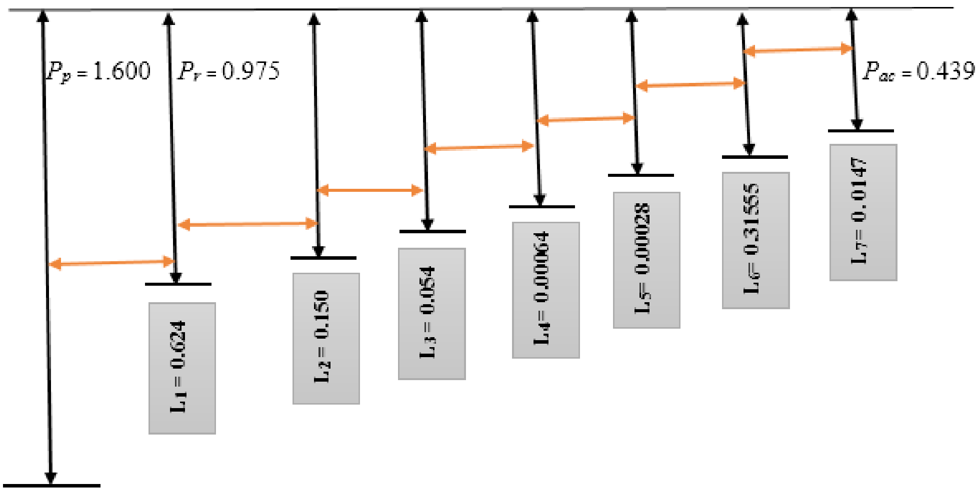

Figure 5. Productivity losses diagram for tire curing assembly line.

4. Conclusion

Attributable to enhance productivity necessities in modern processing industries, the role of productivity model approach becomes more widespread for probable prediction and decision making. In this work, DMAIC and PACE techniques were applied for considering productivity model analysis in United Rubber Industries Ltd with various productivity bounds that were computed to highlight their role for possible improvement in productivity rate. Through this productivity model, developed for tire curing assembly line of the captioned unit, the output could be thoroughly and visually analyzed with an effective outlook. It is also has been verified that novel productivity model yielded much better results of 3.358% errors in productivity estimating which shows its accuracy as compared to real productivity level at different workspaces. Current productivity model approach may be helpful for automatic manufacturing units based on continuous assembly

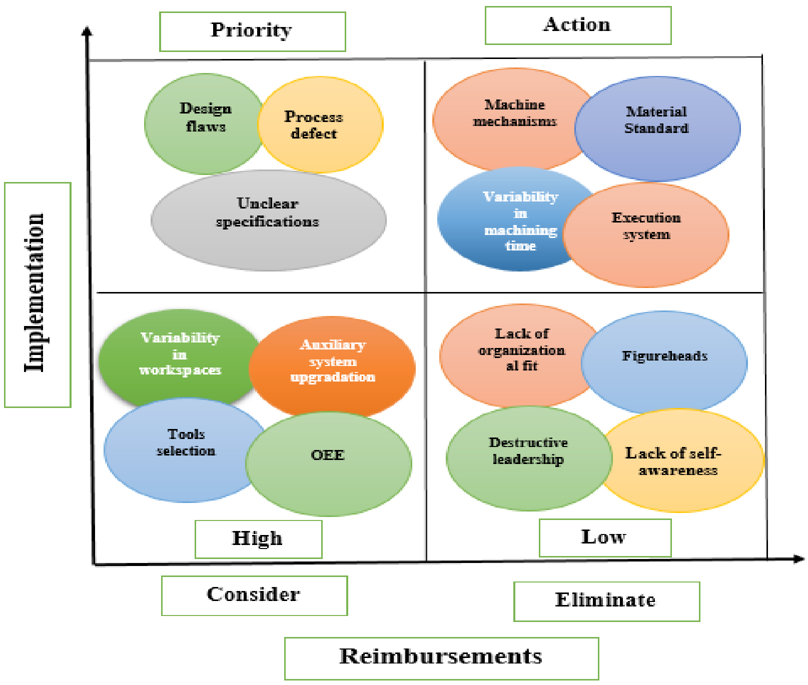

Figure 6. PACE prioritization matrix for productivity model.

line facilities using the DMAIC and PACE analysis for investigating the potential manufacturing bounds that could improve their current manufacturing system.

Acknowledgements

This research work has been expedited by Sarhad University of Science and Information Technology, Peshawar, Pakistan and Uniter Rubber Industries. I am really thankful to my supporting colleagues from Voronezh State University of Engineering and Technology, Russian Federation who provided awareness and proficiency that helped in completing the research.

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