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An Assessment of Sustainability for Turning Process in an Automobile Firm

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Abstract

The concept of Sustainable Manufacturing (SM) has emerged out as a key alternative to improving the performance of machining processes. Though there are many descriptive frameworks available in the literature to assess sustainability still, they are difficult to implement in manufacturing industries due to the limitation on quantifying certain parameters. This paper tends to present a sustainability assessment framework for turning process with respect to the manufactured product in the case industry from the economic and environmental point of view using empirical relations after conducting the experiments at full tool wear criteria. The results are expected to provide an understanding to the industry professionals on the difference between three machining scenario's concurrent to operating conditions being followed in the industry by giving more weightage to economic and environmental indicators separately. In addition to this, a social sustainability assessment framework has also been proposed after consultation with few manufacturing industries in order to make it easy for them to adapt and enhance the sustainability of machining process.

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Keywords: Sustainable Manufacturing; Dry and Wet Machining Process; Sustainability Assessment; Grey Relational Analysis.

1. Introduction

Sustainability plays a key role in integrating economic, environmental and social dimensions with supply chain management systems. The manufacturing sector is one of the most important domain whose performance critically affects the growth of any organization. Thus, there is a need to implement sustainability initiatives to enhance the performance of this sector. Sustainable Manufacturing (SM) has thus been defined as transforming materials into finished products utilising technologies which ultimately reduces "energy consumption, emission of greenhouse gases, generation of waste, and use of non-renewable or toxic materials" [1]. In India itself, the manufacturing sector accounts for 14-18% share in Indian GDP [2] and demands proper attention for the growth of Indian economy. There is already an enormous pressure on manufacturing industries to reduce the impact of their activities on the environment and balance their economic and social aspects. However, the increasing risk of depletion of non-renewable resources in addition to waste generation further escalates the need for implementing sustainable manufacturing initiatives [3]. Since, a large number of machining processes are involved in manufacturing a product, thus, it becomes necessary to consider the sustainability implementation at process level to enhance the performance of manufacturing sector [4].

Turning process being one of the most fundamental material removal processes is employed in almost every manufacturing industry and involves various sustainability concerns to be addressed. One such issue is the amount of energy consumed by this sector which is nearly half of the consumption of the world and has almost doubled in last 60 years [5]. Another concern is related to the harmful effects of coolant on both environment and worker's health. Further, the machine tools are responsible for more than 99% [6] of their impact on the environment even though their operating efficiency is not more than 30% [7]. In the case of cutting quality; the preferred operating conditions of surface roughness and cutting temperature are reverse to each other and this need to be suitably optimised for enhanced performance. As far as literature is concerned, there exist various frameworks that take into consideration economic and environmental issues, but no such elaborate framework is present in the case of social issues. Thus, there is a need for a comprehensive framework to assess the current level of performance for turning process and further helps in enhancing it by suitably optimising operating conditions.

Based on the above discussion, it can be inferred that a suit-

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able sustainability assessment framework needs to be developed which takes into account all important aspects affecting the sustainable performance of the process. This study takes into consideration an industrial process wherein the results for turning process are obtained by conducting experiments in three different operating conditions. The conditions at which the results for various economic and environmental indicators are evaluated are wet turning based on process parameters of case industry; dry turning again based on parameters of industry and lastly dry turning at optimal process parameters mentioned in the handbook. This study thus helps in assessing the sustainable performance of turning process using validated empirical relations and can be extended to other machining processes. The proposed framework will thus help the professionals to incorporate the results in "Design for Sustainability" approach to make their process and product sustainable. In addition to this, a tentative framework for social sustainability assessment has also been proposed at initial stages which will be applied by collecting data from the concerned stakeholders. Thus, the primary objective of this study is to assist the industry professionals in evaluating the performance of machining process and guiding them in further enhancing it.

2. Indicators for Sustainability Assessment

The focus of most of the sustainability assessment frameworks have been found to be at product level [8] which needs to be extended to process level since the process sustainability mostly affects the performance of the manufactured product. This study presents a consolidated list of sustainable manufacturing parameters which can usually be considered for a manufacturing process against economic, environmental and social dimensions after a thorough literature review [9].
The tentative list of parameters for the economic dimension is as follows:

Production Cost: Actual Machining Cost; Machine Idle Cost; Cutting and Lubrication Fluid Cost; Cost of by-product treatment; Machine Tool Usage Cost.

Cutting Quality: Cutting Temperature; Machining induced variations; Surface Roughness.

Production Rate: Cutting Power; Material Removal Rate.

Process Management: Improvement of material/energy consumption; Performance Measurement.

Similarly, the tentative list of parameters for the environmental dimension is as follows:

Water Intensity: Consumption of water per unit of output; Source of water for the process.

Energy Intensity: Energy consumed per unit of output; Renewable proportion of energy consumed.

Materials: Hazardous materials (kg/product); Chemicals (litres/product); Raw materials (kg/product); Material composition (%); Distance from source (km/product).

Waste Management: Weight of releases into air (GHG Emissions) from production process; Weight of releases into surface water from production process; Weight of transfers into disposal from production process (consumables, chips, scraps); Weight of transfers for treatment from production process; Weight of transfers to recycling from production process (chips and scraps); Weight of transfers for energy recovery from production process; Consumables reuse ratio; Wastage and Spill over during production; Mass of coolant loss.

Environmental Regulations.

Lastly, the tentative list of parameters for the social dimension is as follows:

Worker Health: Chemical Contamination of working environment; Mist/dust level; Physical Load Index; Noise Level; Health related absenteeism rate; Admitted level of emissions and waste from machining operations.

Worker Safety: Exposure to toxic chemicals; Exposure to high energy components; Number of occupational accidents; Near Misses; Operator Risk Level; Ergonomic Design of human interface.

Labor Relations: Hourly Wages; Working Hours; Workload; Community Engagement; Local Employment.

Training and Education: Average Number of Hours of training per operator; Required Skill Level.

However, in this study, the parameters relevant to turning process have only been considered based on a similar survey conducted between researchers and industry professionals [4] and suitably highlighted in the next section.

3. Research Methodology

In this study, a large-scale automobile firm has been considered wherein turning of AISI 4140 alloy steel is being done using carbide inserts (DNMG 150608-LM-TN2000) to manufacture an automobile component. The length of the component is 439.75 mm with a diameter of 65 mm and nose radius of the insert is 0.8 mm. The experiments were conducted at full tool wear criteria for three machining scenarios. In the first case, experiments are done at process parameters (204.204 m/min speed, 0.25 mm/rev feed, 1.5 mm depth of cut) being followed in the case industry under wet conditions to evaluate various economic and environmental indicators. In the second case, the same set of operating conditions were adopted under dry conditions to assess the difference in different indicators with respect to wet machining scenario. However, in third case, experimental investigations were carried out on the basis of optimal parameters (160 m/min speed, 0.4 mm/rev feed, 1 mm depth of cut) as suggested by Handbook [10] for suitable tool material combination under dry conditions to identify the extent to which process can be made sustainable. All the indicators have been evaluated for a period of six months in order to get proper differentiation between wet and dry scenario's since the coolant replacement is generally done after six months in the concerned industry. The details of indicators utilised for sustainability assessment have been provided as follows:

3.1. Sustainability Assessment for Machining Process

This section presents the required details on the indicators utilised to evaluate sustainability along with suitable references based on which calculations are done for some indicators whereas some indicators have been determined experimentally. In addition to this, grey relational analysis has also been explained in brief that is employed to compare the sustainability scores for three machining scenarios.

3.1.1. Economic Assessment

Economic assessment focuses on material removal rate, tool life/edge, production rate/edge, surface roughness and production cost per component that has been explained as follows:

1. **Material Removal Rate (M.R.R.)** (cm^3/sec): It is defined as the product of cutting speed (v), feed (f) and depth of cut (d) [11].
$$M.R.R. = \frac{v \times f \times d}{60} \quad (1)$$
2. **Tool-Life/edge (T.L./edge)** (min): Tool life has been determined experimentally in minutes till it reached its flank wear criterion of 300 μm by taking measurements using Stereo Zoom Microscope after every 3-4 passes.
3. **Production Rate/edge (P.R./edge)**: It is an important indicator of productivity and refers to the number of components turned per cutting edge till its complete wear.
$$P.R./edge = \frac{T.L./edge}{\text{Cutting Time/component}} \quad (2)$$
4. **Surface Roughness (R_a)**: It refers to the surface integrity of the machined surface and has been determined experimentally using Talysurf Surface Profilometer.
5. **Production Cost/component (P.C./comp)**: It has been determined on the basis of important aspects such as labour costs (involving time during part handling, machining, idle time, downtime); tooling cost; energy costs (cutting energy, basic energy, idle energy, downtime energy); coolant preparation costs and its disposal; programming cost for complete batch and raw-material cost [12]. The costs for CNC programming and coolant related issues have been calculated over six months period as per the coolant replacement cycle followed in the industry.

3.1.2. Environmental Assessment

Environmental assessment focuses on energy consumption per component, carbon emissions per component, cutting temperature and coolant consumption per component and are explained as follows:

1. **Energy Consumption (E.C./comp)** (kWh): In this study, four main components of energy consumption have been considered which are explained as follows:
   (a) Cutting Energy (E_c): It refers to the amount of energy consumed during the actual cutting process and has been calculated based on the cutting time (T_c) (in sec) and forces (F) (in N) generated measured through Kistler 9129AA - 3 Component, Dynamometer.
   $$E_c = \frac{Fv}{60000} \times \frac{T_c}{3600} \quad (3)$$
   (b) Basic Energy (E_b): This refers to the amount of basic power (P_b) spent in loading and unloading of the component with intermittently cleaning of the machine along with time spent in changing the worn out edge of tool [13].
   $$E_b = \frac{P_b(kW) \times (T_{l,u,cl} + T_{toolchange})(sec)}{3600} \quad (4)$$
   (c) Downtime Energy (E_d): This refers to the amount of basic power spent in the activities outside the process such as programming for complete batch, coolant preparation and cleaning of the tank. Thus, this energy is calculated based on the number of components turned till coolant replacement cycle.
   $$E_d = \frac{P_b(kW) \times T_{downtime}(hr)}{\text{No. of components turned}} \quad (5)$$
   (d) Idle Energy (E_i): This energy takes into account the air-cutting time during which the power of coolant (P_{cl}), spindle (P_s) and axis motor (P_a) are consumed continuously.
   $$E_i = \frac{(P_{cl} + P_s + P_a)(kW) \times T_{air-cut}(sec)}{3600} \quad (6)$$
2. **Carbon Emissions (C.E./comp)** (kg CO_2): A detailed framework has been recently presented in the literature to estimate the amount of carbon emissions for CNC machining systems [14] based on the carbon emissions factors (C.E.F) of electricity, tools, coolant, materials and mass of insert (M_{tl}) and chip (M_{chip}). Thus, this, study tends to apply the above mentioned framework and evaluate the carbon emissions caused by production of; electricity required for operating machines (CE_{elect}), carbide inserts for cutting operation (CE_{tl}), cutting fluids for cooling purposes (CE_{cl}), oil production (CE_{oil}), waste fluid disposal (CE_{wc}), raw materials (CE_m) required for production and chips (CE_{ch}) for which some of basic relations have been provided as follows:
$$CE_{elect} = CEF_{elect} \times (E_{c+b+d+i}) \quad (7)$$
$$CE_{tl} = \frac{T_c}{T.L.} \times CEF_{tl} \times M_{tl} \quad (8)$$
$$CE_{cl} = \frac{T_{c+l,u,cl+toolchange+air-cut}}{T_{coolant}} \times (CE_{oil} + CE_{wc}) \quad (9)$$
$$CE_m = CEF_m \times M_{chip} \quad (10)$$
$$CE_{chip} = CEF_{chip} \times M_{chip} \quad (11)$$
3. **Coolant Consumption (C.C./comp)** (ltr/comp): In this study, the concentration of oil to water as per industry usage has been 1:20. Thus, the amount of oil and water used till life cycle of coolant (being six months) has been measured and subsequently, the oil and water consumption per component has been determined based on the number of components turned in that much time duration.
4. **Cutting Temperature** (°C): The temperature rise at tool-chip interface has been calculated using the experimentally determined equation for a variety of work materials [15] and suitably validated for AISI 4140 alloy steel as well [16].
$$\Delta T = 0.4\frac{U}{\rho C}\left(\frac{vt_o}{K}\right)^{0.333} \quad (12)$$
where;
ΔT is mean temperature rise at tool-chip interface in °C.
U is specific cutting energy in N-m/mm^3.
ρC is the volumetric specific heat of material in J/mm^3-°C.
v is cutting speed in mm/sec.
t_o is chip thickness before cut (mm) approximated as "$feed \times Sin\phi$"; ϕ being principal cutting edge angle.
K is thermal diffusivity of work material in mm^2/sec.

3.1.3. Social Assessment

In the case of social sustainability assessment, a unique framework has been proposed in consultation with industry professionals wherein the responses from all the concerned stakeholders can be obtained on a scale of 1-5 and suitably graded. Various social indicators relevant to machining process have been shortlisted from Section 2 wherein the selected indicators have been divided into three categories. In the first category, the indicators are rated by the respective department heads or supervisors for workers respectively regarding performance issues, worker skills and behavioral issues. In the second category, the indicators are rated by the workers themselves regarding issues such as management support, job prospects, working conditions and extent of government support. Finally, in the third category, the remaining indicators are rated by third party audit members regarding various organisational and worker issues such as workers compliance with regulatory requirements set by government e.g. waste and energy aspects, organizational performance, worker issues, etc. Thus, based on the responses, GRA technique is applied to assess the social sustainability index of the organization the details of which have been suitably provided in Section 4.

3.2. Grey Relational Analysis (GRA)

Grey systems theory relates to incomplete and uncertain information. In this theory, the presence of complete information is represented by white system whereas black system denotes the absence of information [17]. However, the necessary steps for applying this technique [18] has been explained as follows:

1. **Preparing data for analysis**: In this step, the data is normalised in the range of 0-1 depending on either "higher-the-better" criteria e.g. in the case of Tool Life, Production Rate, etc. or "lower-the-better" criteria e.g. for Energy Consumption, Production Cost, etc. The data normalisation for higher-the-better criteria is done as follows:

$$x_{ij} = \frac{y_{ij} - Min(y_{ij}, i = 1, 2, ..., m)}{Max(y_{ij}, i = 1, 2, ..., m) - Min(y_{ij}, i = 1, 2, ..., m)} \quad (13)$$

Similarly, the data normalisation for "lower-the-better" criteria is done as follows:

$$x_{ij} = \frac{Max(y_{ij}, i = 1, 2, ..., m) - y_{ij}}{Max(y_{ij}, i = 1, 2, ..., m) - Min(y_{ij}, i = 1, 2, ..., m)} \quad (14)$$

2. **Determining Grey Relational Coefficients (GRC)**: The coefficients tend to determine the degree of closeness between comparability sequence and reference series as follows:

$$\gamma(x_{0j}, x_{ij}) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{ij} + \zeta\Delta_{max}} \text{ for i = 1,2,...,m \& j = 1,2,...,n} \quad (15)$$

where;
$\gamma(x_{0j}, x_{ij})$ is coefficient between x_{0j} and x_{ij}.
$\Delta_{ij} = |x_{0j} - x_{ij}|$,
$\Delta_{min} = Min(\Delta_{ij}, i = 1, 2, ..., m; j = 1, 2, ..., n)$,
$\Delta_{max} = Max(\Delta_{ij}, i = 1, 2, ..., m; j = 1, 2, ..., n)$,
ζ is distinguishing coefficient and $\zeta \in \{0, 1\}$.

3. **Calculating Grey Relational Grades (GRG)**: It is calculated by assigning suitable weightage to each attributes as follows:

$$\Gamma(x_0, x_i) = \sum_{j=1}^{n} w_j \gamma(x_{0j}, x_{ij}) \text{ for i = 1,2,...,m} \quad (16)$$

where;
w_j is weightage assigned to different indicators.

4. Results and Discussion

Table 1 presents an assessment of various economic and environmental indicators for three machining scenarios using empirical relations highlighted from literature as follows:

Table 1. Results for S.M. Indicators

Condition	v	f	d	M.R.R.	T.L.	P.R.	R_a	P.C.	C.C.	Temp	C.E.	E.C.
Wet	204	0.25	1.5	1.276	56	31.836	3.349	637.37	0.0355	1096.291	3.427	0.1837
Dry	204	0.25	1.5	1.276	14	7.959	1.966	647.5	0	1126.175	3.595	0.2008
Opt. Dry	160	0.4	1	1.067	20	14.220	5.760	640.74	0	1097.470	2.3901	0.1543

The differences in wet and dry machining scenarios at same operating conditions have been suitably highlighted in Table 1 wherein the wet scenario proves to be preferable over dry machining due to enormous economic benefits concerning tool-life, production rate and production cost. However, the dry machining scenario is more favourable in terms of surface finish of the machined surface. Overall, it can be observed that the wet turning process is more inclined towards economic aspects whereas the optimal dry machining scenario is more favourable to environmental concerns.

Based on above observations, the results of grey relational analysis have again been presented in two scenarios wherein suitable weightages have been allotted to two critical aspects of economic and environmental dimensions being production cost and energy consumption respectively. Table 2 presents the results for grey relational coefficients and grades for Case I where 50% weightage has been allotted to energy consumption and rest 50% weightage has been distributed equally amongst all other indicators to find most preferable machining scenario from the environmental point of view.

Table 2. Grey Relational Coefficient & Grade Values for Case I

Weightages	Case I			0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.5	GRG-I
Condition	v	f	d	M.R.R.	T.L.	P.R.	R_a	P.C.	C.C.	Temp	C.E.	E.C.	
Wet	204	0.25	1.5	1	1	1	0.578	1	0.333	1	0.368	0.442	0.613
Dry	204	0.25	1.5	1	0.333	0.333	1	0.333	1	0.333	0.333	0.333	0.458
Opt. Dry	160	0.4	1	0.333	0.368	0.404	0.333	0.601	1	0.927	1	1	0.810

Similarly, Table 3 presents the results for grey relational coefficients and grades for Case II where 50% weightage has been allotted to production cost and rest 50% weightage has been equally distributed amongst all other indicators to find suitable machining scenario from the economic point of view.

Table 3. Grey Relational Coefficient & Grade Values for Case II

Weightages	Case II			0.062	0.062	0.062	0.062	0.5	0.062	0.062	0.062	0.062	GRG-II
Condition	v	f	d	M.R.R.	T.L.	P.R.	R_a	P.C.	C.C.	Temp	C.E.	E.C.	
Wet	204	0.25	1.5	1	1	1	0.578	1	0.333	1	0.368	0.442	0.858
Dry	204	0.25	1.5	1	0.333	0.333	1	0.333	1	0.333	0.333	0.333	0.458
Opt. Dry	160	0.4	1	0.333	0.368	0.404	0.333	0.601	1	0.927	1	1	0.636

Thus, based on the results presented in Table 2 and 3, it can be inferred that the grade score is maximum for the optimal dry process being 0.810 if higher importance is given to energy consumption i.e. the machining scenario corresponding to which energy consumed is minimum thus being more environmentally sustainable. However, the grade score is higher for wet machining scenario being 0.858 if more importance is given to economic aspects. Hence, it can be concluded that the current scheme of operating conditions being followed in the industry is more inclined towards economic issues even though many organizations proclaim to focus on environmental issues. It is interesting to find that, even if the current operating conditions are shifted from wet to optimal dry with the same cutting tool, the decrease in grade is only by 0.048, and yet the inclination towards environmental perspective can be enhanced. Thus, to progress in the direction of sustainable performance, efforts need to be taken to modify the operating parameters and can be shifted to optimal dry conditions as suggested by handbook to enhance the level of their sustainable performance.

In order to assess the social sustainability index of the machining process, relevant indicators discussed in Section 2 have been considered on which the GRA technique has then been applied suitably. In the preliminary attempt, the analysis has been done based on the responses collected from concerned stakeholders presented in Table 4; being one department head, one engineer, five workers and two auditors with respect to turning process only. However, average values for some indicators have been considered where more than one response has been recorded which has then been rounded off to the nearest integer.

Table 4. Framework for assessing Social Sustainability

S. No	Social Indicators	W_1	W_2	W_3	W_4	W_5	Ranked By:
1	Worker's Productivity	3.00	3.00	4.00	5.00	4.00	Dept. Head
		3.00	4.00	4.00	4.00	3.00	Engineer 1
		3.00	4.00	4.00	5.00	4.00	Average Rating
2	Relations with Other Workers	4.00	4.00	5.00	5.00	4.00	Dept. Head
		3.00	4.00	4.00	4.00	4.00	Engineer 1
		4.00	4.00	5.00	5.00	4.00	Average Rating
3	Worker's Skills	4.00	3.00	4.00	5.00	4.00	Dept. Head
		3.00	3.00	4.00	5.00	3.00	Engineer 1
		4.00	3.00	4.00	5.00	4.00	Average Rating
4	Job Rotation Flexibility	3.00	2.00	3.00	4.00	3.00	Dept. Head
		3.00	3.00	4.00	4.00	3.00	Engineer 1
		3.00	3.00	4.00	4.00	3.00	Average Rating
5	Job Punctuality	3.00	3.00	3.00	4.00	3.00	Dept. Head
		4.00	3.00	2.00	4.00	4.00	Engineer 1
		4.00	3.00	3.00	4.00	4.00	Average Rating
6	Top Management Support	3.00	3.00	3.00	4.00	3.00	Ranked by all Workers themselves.
7	Job Satisfaction	4.00	3.00	4.00	4.00	4.00	
8	Conducive Work Environment	3.00	2.00	3.00	3.00	3.00	
9	Extent of Government Support:						
9.1	Awareness on Sustainable Manufacturing Initiatives	2.00	1.00	2.00	2.00	1.00	
9.2	Technological Upgradation	1.00	1.00	1.00	2.00	1.00	
9.3	Financial Support (in form of loans, etc.)	2.00	3.00	2.00	3.00	2.00	
10	Worker's compliance with regulatory requirements:						
10.1	Required Products Quality	3.00	3.00	4.00	5.00	4.00	Auditor 1
		4.00	4.00	5.00	5.00	4.00	Auditor 2
		4.00	4.00	5.00	5.00	4.00	Average Rating
10.2	Waste Management Policy	3.00	3.00	3.00	4.00	3.00	Auditor 1
		4.00	2.00	3.00	4.00	4.00	Auditor 2
		4.00	3.00	3.00	4.00	4.00	Average Rating
10.3	Energy Conservation Policy	4.00	2.00	4.00	4.00	3.00	Auditor 1
		3.00	2.00	3.00	4.00	3.00	Auditor 2
		4.00	2.00	4.00	4.00	3.00	Average Rating
10.4	Operational Safety	3.00	2.00	4.00	4.00	3.00	Auditor 1
		4.00	3.00	3.00	5.00	4.00	Auditor 2
		4.00	3.00	4.00	5.00	4.00	Average Rating
10.5	Personnel health and hygiene	3.00	3.00	3.00	4.00	3.00	Auditor 1
		3.00	2.00	3.00	3.00	3.00	Auditor 2
		3.00	3.00	3.00	4.00	3.00	Average Rating

It can be observed in Table 4 that for the first set of indicators the department head and an engineer give their responses on a scale of 1-5 for the five workers involved in turning process. In the second category, all the five workers themselves rate the indicators concerning organizational and the government issues. Finally, two internal auditors have also been referred to consider their views from the inspection point of view to assess the organizational performance. Thus, the benefit of this framework is that it is comprehensive in nature and takes into consideration the views of all concerned stakeholders on all important social indicators relevant to organizational performance and turning process itself.

Further, based on the application of GRA technique for Likert scale data [19], Table 5 presents the grade values for all selected social indicators which resemble the performance index of the organization wherein the Social Sustainability Index has been evaluated by taking the mean of all grade values.

Table 5. Social Sustainability Index for Turning Process

S. No	Social Indicators	W_1	W_2	W_3	W_4	W_5	GRG
1	Worker's Productivity	0.5000	0.6667	0.6667	1.0000	0.6667	0.700
2	Relations with Other Workers	0.6667	0.6667	1.0000	1.0000	0.6667	0.800
3	Worker's Skills	0.6667	0.5000	0.6667	1.0000	0.6667	0.700
4	Job Rotation Flexibility	0.5000	0.5000	0.6667	0.6667	0.5000	0.567
5	Job Punctuality	0.6667	0.5000	0.5000	0.6667	0.6667	0.600
6	Top Management Support	0.5000	0.5000	0.5000	0.6667	0.5000	0.533
7	Job Satisfaction	0.6667	0.5000	0.6667	0.6667	0.6667	0.633
8	Conducive Work Environment	0.5000	0.4000	0.5000	0.5000	0.5000	0.480
9.1	Awareness on Sustainable Manufacturing Initiatives	0.4000	0.3333	0.4000	0.4000	0.3333	0.373
9.2	Technological Upgradation	0.3333	0.3333	0.3333	0.4000	0.3333	0.347
9.3	Financial Support (in form of loans, etc.)	0.4000	0.5000	0.4000	0.5000	0.4000	0.440
10.1	Required Products Quality	0.6667	0.6667	1.0000	1.0000	0.6667	0.800
10.2	Waste Management Policy	0.6667	0.5000	0.5000	0.6667	0.6667	0.600
10.3	Energy Conservation Policy	0.6667	0.4000	0.6667	0.6667	0.5000	0.580
10.4	Operational Safety	0.6667	0.5000	0.6667	1.0000	0.6667	0.700
10.5	Personnel health and hygiene	0.5000	0.5000	0.5000	0.6667	0.5000	0.533
	Index for Social Sustainability (according to Mean of Social Indicators)						**0.587**

Based on the above analysis as shown in Table 5, following inferences can be made:

1. The social sustainability index for the organization in the current situation has been found to be 0.587 and demands strategic attention to enhance the performance.
2. The social indicators emerging from analysis with highest grades have been discussed as follows:
    - Required Products Quality and Relation's with other Worker's have received the highest grade of 0.8 which signifies the fact that organization is socially integrated and focussed towards quality norms to satisfy the customer requirements.
    - Worker's Productivity, Skill Level and Operational Safety are amongst the next set of social indicators which have received the grade value of 0.7 reflecting the appropriate level of worker's knowledge and skills to achieve the required production rate following relevant safety norms though there is still scope for improvement.
    - The level of job satisfaction has been found to be at just above average with grade value of 0.633 because there is a little scarcity of required jobs in the market and thus, workers are bound to work at low wages with the higher workload.
3. However, the indicators depicting poor performance are mostly related to government issues and have been discussed as follows:

- Although there are various financial schemes initiated by the government, yet it is hard to find their implementation at ground level with grade value of 0.44 due to pick and choose policy of nodal agencies in disbursal of grants and other schemes thus affecting the growth of the industry.
- The awareness regarding sustainable manufacturing initiatives is very little amongst industry professionals, with grade value of 0.373, leading to the poor implementation of sustainability in the manufacturing sector.
- The industry professionals find the government technical institutions which play a significant role in enhancing the technical know-how of not much help with grade value of 0.347 since the available technology in the industry is even far superior to current infrastructure in government institutions.

5. Conclusion

This paper tends to give a sustainability assessment framework for turning process based on three operating conditions i.e. first being industry process under wet conditions; secondly, the same process repeated under dry conditions to determine the difference between results and lastly, based on the optimal value as suggested by the handbook. Along with this, the study also proposes a social sustainability assessment framework that takes into account the views of all concerned which collectively affect the sustainable performance of the process. The proposed framework is expected to help the industry professionals in assessing the sustainable performance of the concerned machining process and further, take into account the suitable measures necessary to enhance the performance. The main highlights of the study have been presented as follows:

1. The wet machining scenario being followed in the industry has been found to be inclined more towards economic perspective than for environmental concerns, and thus, there is a need for strategic modification in the operating conditions which have a balanced approach towards economic and environmental concerns leading to a sustainable scenario.
2. The optimal dry conditions as suggested by the handbook have been found to be an excellent alternative to current machining scenario with grade score of 0.810 since it helps in minimizing the negative impact of the process on the environment and at the same time has a minimum difference between production cost in both the scenarios.
3. The social sustainability index of 0.587 as per current situation is still low and needs strategic improvisation with support from the government to enhance the social index.

There is also a scope for extending the present work by assessing the sustainable performance of machining processes such as milling, grinding, etc. In addition to this, it will be interesting to evaluate product sustainability by integrating the sustainability assessment frameworks for all machining processes involved in the manufacturing of the complete product. Given advanced machining processes such as additive manufacturing; this framework can also be helpful in comparing the sustainability of the product as compared to traditional methods.

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