sustainability

MDPI

Article

A Dynamic Simulation Model for Understanding Sustainability of Machining Operation

Tess Moran, Rod MacDonald and Hao Zhang *

School of Integrated Sciences, James Madison University, Harrisonburg, 22807, USA
* Correspondence: zhang9hx@jmu.edu

Model Variable and Equations.

	Equation	Properties	Units
	Top-Level Model:		
Average_Roughness(t)	Average_Roughness(t - dt) + (Net_Change_in_Quality) * dt	INIT Average_Roughness = 85	roughness
Cost(t)	Cost(t - dt) + (Cost_Accumulation) * dt	INIT Cost = 0	dollars
Energy(t)	Energy(t - dt) + (Accumulation_of_Energy) * dt	INIT Energy = 0	kW*h
Environmental_Impacts(t)	Environmental_Impacts(t - dt) + (Impact_Accumulation) * dt	INIT Environmental_Impacts = 0	kg CO2e
Tool_Wear(t)	Tool_Wear(t - dt) + (tool_wear_rate - Tool_replacement) * dt	INIT Tool_Wear = 0.01	One thousands of an inch
Accumulation_of_Energy	Cutting_Power/Adjustment_time		kW*h/Minutes
Cost_Accumulation	(((Cost_of_Tools+Cost_of_Energy+Cost_of_Material)))/100		dollars/minutes
Impact_Accumulation	Environmental_Impact_Converter_For_Tools+ Environmental_Impact_Converter_For_Material+Environmental_Impact_Converter_for_Energy		kg CO2e/minutes
Net_Change_in_Quality	(Surface_Finish_Roughness-Average_Roughness)/Adjustment_Time_for_Quality		roughness/Minutes
Tool_replacement	IF (Ratio_of_Tool_Wear_to_Tolerance_Standard >= 1) THEN (Tool_Wear) ELSE (0)		One thousands of an inch/Minutes
tool_wear_rate	Tool_Replacement_On_Wear_Rate*Tool_life		One thousands of an inch/Minutes
Adjustment_time	1		Minutes
Adjustment_Time_for_Quality	50		Minutes
B1	LOOPSCORE(tool_wear_rate,Tool_Wear,Ratio_of_Tool_Units,Effect_of_Newness_on_Tool_Wear,Tool_life)		dmnl
B2	LOOPSCORE(Tool_replacement,Tool_Wear,Ratio_of_Tool_Wear_to_Tolerance_Standard)		dmnl
B3	LOOPSCORE(tool_wear_rate,Tool_Wear,Ratio_of_Tool_Wear_to_Tolerance_Standard,Tool_Replacement_On_Wear_Rate)		dmnl
B4	LOOPSCORE(Tool_replacement,Tool_Wear)		dmnl

"C_value_(Wear_Per_Cutting_Speed)"	.0033 {1368.7}	One thousands of an inch/Revolutions
Cost_Accumulation_per_processing_time	Cost_Accumulation/Processing_Time	dollars/unit
Cost_of_Energy	Accumulation_of_Energy*Price_per_kWh	dollars/minutes
Cost_of_Material	Material_Removal_Rate*"Price_per_in^3_steel"	dollars/minutes
Cost_of_Tools	IF(Tool_replacement>124)THEN(Cost_per_Tool)ELSE(0)	dollars/minutes
Cost_per_Tool	15	dollars/tool
Cutting_Length	12	Inches/unit
Cutting_Power	Cutting_Speed_to_Power_Relationship/"min/hr"	kW*h
Cutting_Speed_to_Power_Relationship	GRAPH(RPM*"RPM_to_m/min") Points: (0.01, 0.0), (0.5, 0.02), (0.75, 0.03), (1, 0.04), (1.5, 0.05), (2, 0.07), (5, 0.18), (20, 0.7), (50, 1.76), (100, 3.52), (200, 7.04), (500, 17.61), (1000, 35.22), (1500, 52.84), (2000, 70.45), (2500, 88.06), (3000, 105.67), (3500, 123.29)	kW/Minutes
density_of_carbide_tool	0.25613	kg carbide/in^3
density_of_steel	0.12862	kg steel/in^3
Depth_of_Cut	0.236	Inches
Effect_of_Newness_on_Tool_Wear	GRAPH(Ratio_of_Tool_Units) Points: (0.000, 2.500), (0.100, 1.500), (0.200, 1.000), (0.300, 1.000), (0.400, 1.000), (0.500, 1.000), (0.600, 1.000), (0.700, 1.000), (0.800, 1.000), (0.900, 1.000), (1.000, 1.000)	Dimensionless
Effect_of_Ratio_of_SQF_to_Normal	GRAPH(Ratio_of_Surface_Quality_to_Normal) Points: (0.00, 1.000), (1.00, 1.000), (2.00, 1.000), (3.00, 1.100), (4.00, 1.200), (5.00, 1.300), (6.00, 1.500), (7.00, 1.600), (8.00, 1.900), (9.00, 2.200), (10.00, 2.400)	Dimensionless
Effect_of_Tool_Wear_to_Tolerance_Standard	GRAPH(Ratio_of_Tool_Wear_to_Normal_Tool_Replacement) Points: (0.000, 1.00), (0.100, 1.00), (0.200, 1.00), (0.300, 1.00), (0.400, 1.00), (0.500, 2.06), (0.600, 3.09), (0.700, 4.36), (0.800, 4.64), (0.900, 4.91), (1.000, 9.96)	Dimensionless
Environmental_Impact_Converter_for_Energy	Impact_Factor_for_Energy*Accumulation_of_Energy	kg CO2e/minutes
Environmental_Impact_Converter_For_Material	Material_Removal_Rate*density_of_steel*Impact_Factor_For_Steel	kg CO2e/minutes
Environmental_Impact_Converter_For_Tools	Volume*density_of_carbide_tool*Impact_Factor_for_Carbide_Tool	kg CO2e/minutes
Feed	0.0017	inches/revolutions/edges
Feed_Rate	Number_of_Cutting_Edges*Feed*RPM	inches/minutes
Impact_Factor_for_Carbide_Tool	69	kg CO2e/kg carbide
Impact_Factor_for_Energy	7090	kg CO2e/kW*h

Impact_Factor_For_Steel	2.1	kg CO2e/kg steel
Initial_Tool_Replacement_Standard	250	One thousands of an inch
Material_Removal_Rate	Depth_of_Cut*Width_of_Cut*Feed_Rate	in^3/minutes
"min/hr"	60	h/Minutes
n_value	1	Dimensionless
Normal_Cutting_Speed	3000	Revolutions/Minutes
Normal_Smoothness_of_Surface	32	roughness
Normal_Tool_Replacement	250	
Number_of_Cutting_Edges	4	edges
Number_of_Products_Made	1/Processing_Time	unit/minutes
Policy_Test_for_Tool_Replacement	0	Dimensionless
Policy_Time_Step	25	minutes
"Price_per_in^3_steel"	1.28	dollars/in^3
Price_per_kWh	0.00672	dollars/kW*h
Processing_Time	Cutting_Length/Feed_Rate	Minutes/unit
Ratio_of_Cost_to_Roughness	Cost/Average_Roughness	dollars/roughness
Ratio_of_Surface_Quality_to_Normal	Surface_Finish_Roughness/Normal_Smoothness_of_Surface	Dimensionless
Ratio_of_Tool_Units	Tool_Wear/Tool_replacement_standard	Dimensionless
Ratio_of_Tool_Wear_to_Normal_Tool_Replacement	Tool_Wear/Normal_Tool_Replacement	Dimensionless
Ratio_of_Tool_Wear_to_Tolerance_Standard	Tool_Wear/Tool_replacement_standard	Dimensionless
RPM	{250-0.5*Surface_Finish_Quality} Normal_Cutting_Speed*Effect_of_Ratio_of_SQF_to_Normal	Revolutions/Minutes
"RPM_to_m/min"	0.019939	kW/Revolutions
Surface_Finish_Roughness	{128.18-(0.016*Tool_Wear)} Normal_Smoothness_of_Surface*Effect_of_Tool_Wear_to_Tolerance_Standard	roughness
Tool_life	{((Cutting_Speed/C_value)^(1/n_value))+Modifier}(RPM*n_value*"C_value_(Wear_Per_Cutting_Speed)")*Effect_of_Newness_on_Tool_Wear	One thousands of an inch/Minutes
Tool_Replacement_On_Wear_Rate	IF (Ratio_of_Tool_Wear_to_Tolerance_Standard >= 1) THEN (0) ELSE (1)	Dimensionless
Tool_replacement_standard	Initial_Tool_Replacement_Standard*(1+STEP(Policy_Test_for_Tool_Replacement, Policy_Time_Step))	One thousands of an inch
U1	LOOPSCORE(tool_wear_rate,Tool_Wear,Ratio_of_Tool_Wear_to_Tolerance_Standard,Effect_	dmnl

	of_Tool_Wear_to_Tolerance_Standard,Surface_Finish_Roughness,Ratio_of_Surface_Quality_to_Normal,Effect_of_Ratio_of_SQF_to_Normal,RPM,Tool_life)	
Volume	IF(Tool_replacement>222)THEN(Volume_per_Tool)ELSE(0)	inches^3/minutes
Volume_per_Tool	0.0982	inches^3/minutes
Width_of_Cut	0.25	inches

Run Specs	
Start Time	0
Stop Time	240
DT	1/1
Fractional DT	True
Save Interval	1
Sim Duration	1.5
Time Units	Minutes
Pause Interval	0
Integration Method	Euler
Keep all variable results	True
Run By	Run
Calculate loop dominance information	True
Exhaustive Search Threshold	1000