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TOWARDS A STANDARDS-BASED METHODOLOGY FOR EXTENDING MANUFACTURING PROCESS MODELS FOR SUSTAINABILITY ASSESSMENT

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Sustainable manufacturing challenges

- Sustainability assessment tools primarily address environmental impacts
- Available assessment methods for social and economic aspects of sustainability mostly consider physical flows
- Analysis tool challenges
  - Operational deficiencies of analysis applications
  - Analysis applications cannot support system, process, and machine level sustainable manufacturing decisions
  - Data collection and reporting has been the biggest challenge for manufacturers

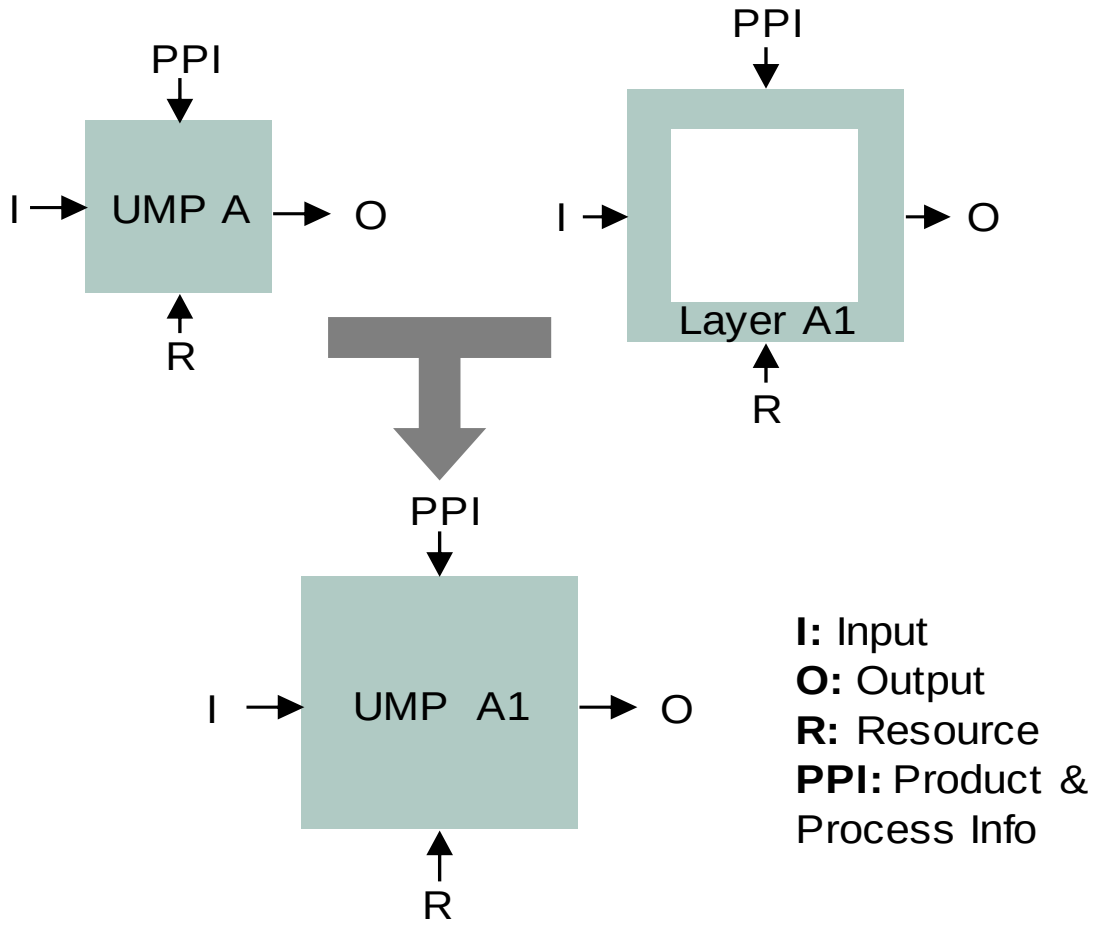
Lozano et al., 2008; Haapala et al., 2009; Reap et al., 2008 ; Lozano et. al., 2012; Gutowski et al., 2006; Lehtinen et al., 2011; Ramani et al., 2012; Chen et al., 2015

Motivation - Identified research deficits

- Previous modeling methods focused on developing information models that are distinct and specific
- Models have to be developed from scratch
- Lacked aspects of reusability and extensibility

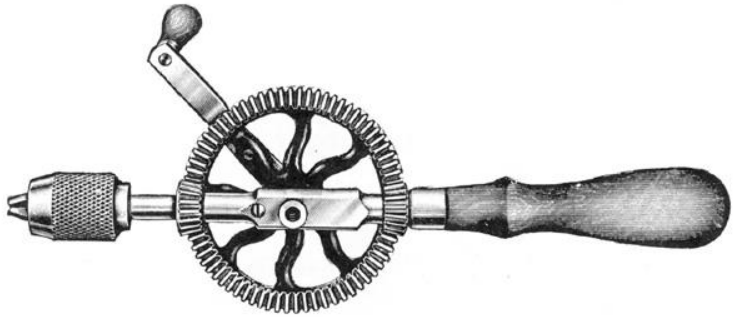
Reusability and Extensibility

- Template (abstraction) model instantiation (Reusability)
- Add layers to instantiation of template model (Extensibility)
- Layers
  - Auxiliary systems
  - Higher order variants



Template model

- A model that completely characterizes the most simplistic instantiation of a manufacturing process that has varying levels of machine configurations
- Example: A manual drill.



Goodell Pratt, 1931

Case study – Manual milling machine

Product and Process Information

F_c – Cutting force	V_r – Volume removed	E_c – Cutting energy
V_c – Cutting speed	MRR – Material removal rate	E_{on} – Onsite energy consumption
f – Feed	W – Tool wear rate	E_{off} – Offsite energy consumption
d – Depth of cut	P_{cut} – Cutting power	E_T – Total energy consumption (*)
T_c – Cutting time	P_m – Power at motor/spindle	c_e – Unit cost of energy
V_i – Initial volume	r_{CO2} – Generation rate of CO_2	C_e – Total cost of energy (*)
V_f – Final volume	r_{CH4} – Generation rate of CH_4	GHG – Mass of greenhouse gas emission (*)
η – Efficiency of motor	r_{NO2} – Generation rate of NO_2	

Inputs
Electrical energy
Workpiece (Raw material/WIP)

Transformation Equations

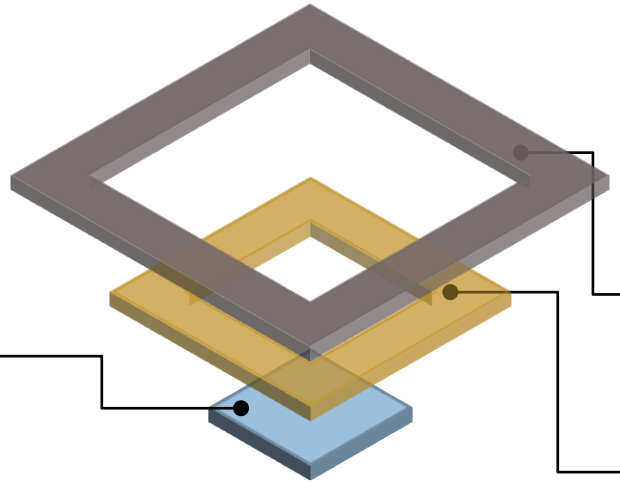
$V_r = V_i - V_f$	$P_m = P_{cut} / \eta$	$E_T = E_{on} + E_{off}$
$MRR = v_c * f * d$	$E_c = P_{cut} * T_c$	$C_e = E_T * c_e$
$P_{cut} = F_c * V_c$	$E_{on} = P_m * T_c$	$GHG = E_T * (r_{CO2} + r_{CH4} + r_{NO2})$

Outputs
Finished part
Waste

Resources
Software, tool list, operator/machine details, fixture

Kara, S. et al., 2011; Kalla, D. et al., 2009; Avram, O.I. et al., 2011

Case study: Two and a half axis milling with lubricant system - 1



Manual milling model (Template)

Lubricant system model (Layer 2)

Two-axis milling model (Layer 1)

Model of two and a half axis milling with lubricant system (Extended model)

Case study : Two and a half axis milling with lubricant system -2

Product and Process Information

F_c – Cutting force	V_r – Volume of material removed	
V_c – Cutting speed	MRR – Material removal rate	
f – Feed	W – Tool wear rate	
d – Depth of cut		
T_c – Cutting time		
V_i – Initial volume	P_{cut} – Cutting power	
V_f – Final volume	P_m – Power at motor/spindle	
n - Efficiency of motor	r_{CO2} – Production rate of CO_2	c_e – Unit cost of energy
	r_{CH4} – Production rate of CH_4	C_e – Total cost of energy
	r_{NO2} – Production rate of NO_2	GHG – Mass of greenhouse gas emissions

Inputs
Electrical energy
Workpiece
(Stock/WIP)

Transformation Equations

$V_r = V_i - V_f$	$P_{cut} = P_s + P_{spec}$	$C_e = E_T * c_e$
$MRR = v_c * f * d$	$P_m = P_{cut} / \eta$	$GHG = E_T * (r_{CO2} + r_{CH4} + r_{NO2})$
$P_{cut} = F_c * V_c$		

Outputs
Finished part
Waste

Resources
Software, tool list, operator/machine details, fixture

Future work

- Characterize data exchange information (linking variables) for composability
- Develop an information exchange framework that includes composability for manufacturing system characterization including information validation
- Realize the framework using a software applications