



Proposal of new eco-manufacturing feature interaction-based methodology in CAD phase

Hadhami Ben Slama, Raoudha Gaha, Abdelmajid Benamara

► To cite this version:

Hadhami Ben Slama, Raoudha Gaha, Abdelmajid Benamara. Proposal of new eco-manufacturing feature interaction-based methodology in CAD phase. International Journal of Advanced Manufacturing Technology, 2019, 106, pp.1057 - 1068. 10.1007/s00170-019-04483-7 . hal-04350984

HAL Id: hal-04350984

<https://hal.science/hal-04350984>

Submitted on 21 Dec 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Proposal of a new based feature-interaction eco-manufacturing methodology on CAD phase

Hadhami BEN SLAMA, Raoudha GAHA, and Abdelmajid BENAMARA

Abstract – Following the many environmental crises of recent decades, a turning point in the awareness of the fragility of ecosystems has been marked, that is to say an environmental awareness. This has contributed to the development of various environmental laws and regulations such as the «Waste Electrical and Electronic Equipment» (WEEE), «Restriction of Hazardous Substances» (RoHS) and «Energy Using Products» (EuP) Directives or the «Registration, Evaluation, Authorization and Restriction of Chemicals» (REACH) Regulation. Then, the productive model of industrial societies is questioned. A greater awareness of environmental issues is emerging. At the beginning and with the aim of minimizing the environmental impacts (EIs), the research work focused essentially on two axes: recycling and chemical substances. The process plan operations order has also an influence on the EIs of a product. In this paper, we propose a new based scenarios methodology by using the feature interactions technology (FIT) and a multi-criteria decision support method (MCDSM) that allows the non-environmental expert designer to have the optimal manufacturing process plan on CAD phase. First, we present our state of art. Then, we introduce our new methodology based on both FIT and MCDSM in order to choose the greenest manufacturing scenario. Finally, a case study of feature interaction will be presented for demonstration purposes.

Keywords: CAD/ Eco-design/ Eco-manufacturing/ Environmental Impact/multi-criteria decision support / Scenarios/ Feature interaction.

Hadhami BEN SLAMA^a, Raoudha GAHA (✉)^b, Abdelmajid BENAMARA^a.

a.Laboratoire Génie Mécanique, Ecole Nationale d'Ingénieurs de Monastir, Université de Monastir, Rue Ibn Aljazzar 5019 Monastir, Tunisie.

b. Laboratoire de Mécanique de Sousse, Ecole Nationale d'Ingénieurs de Sousse, Université de Sousse, BP 264 Sousse Erriadh, Tunisie.

raoudha.gaha@gmail.com

raoudha.gaha@gmail.com.

1. Introduction

Following the many environmental crises of recent decades, a turning point in the awareness of the fragility of ecosystems has been marked, that is to say an environmental awareness. A wide range of environmental problems has emerged. Those problems include anthropogenic climate change (global warming), the acidification of surface water (acid rain), depletion of stratospheric ozone (ozone hole), etc. This has contributed to the development of various environmental laws and regulations such as the «Waste Electrical and Electronic Equipment» (WEEE) [1], «Restriction of Hazardous Substances» (RoHS) [2] and «Energy Using Products» (EuP) [3] Directives or the «Registration, Evaluation, Authorization and Restriction of Chemicals» (REACH) [4] Regulation. Thus, the productive model of industrial societies is questioned hence the birth of the concept of eco-design. Eco-design approaches, aimed at reducing the environmental impacts of products over their entire life cycle, neglect the manufacturing phase. Manufacturing is the transformation of a raw material into a finished product by a process that causes a waste and environmental emissions. Therefore, researchers in this field tend to reduce environmental impacts from the manufacturing phase, where the notion of eco-manufacturing comes from. In this paper, first we present a literature review of works treating the optimization of the manufacturing phase from an environmental point of view. Second, we present a state of the art presenting eco-manufacturing integrating Computer Aided Design (CAD) systems; also, we underline the role of multicriteria decision support methods and the micro/macro-planning in the designer's decision-making regarding the greenest manufacturing scenario. Third, we describe our approach in order to eco-assist designers early in the design process and we validate it on a case study. Finally, we conclude our points and we propose perspectives for this work.

2. Eco-manufacturing: Overview

2.1. Manufacturing Optimization from an environmental point of view

Manufacturing operations consume energy. Overall, they account for 19% of greenhouse gas emissions [5] and 37% of energy consumption [6]. With regard to energy consumption, a lot of methods for energy measurement; monitoring, modeling and optimization are applied to machining systems in order to improve their energy performance. For machining, the improvement of processes that surpass efficiency measures requires the measurement of the energy consumption of machining processes or systems [7], [8].

Energy modeling and optimization are considered as basic measures for energy efficient machining. Energy models can be divided into three categories:

- Linear type cutting energy consumption models which are based on material removal rate (MRR),
- Detailed parameter type cutting energy consumption correlation models
- The process-oriented machining energy consumption model.

In 2016, Feng et al formulated multicriteria optimization approaches for making the best use of energy delivered to the production processes [9]. In 2017, Hu et al introduced a single objective optimization problem minimizing the machine tools energy consumption (MTE) while machining a part [10]. In 2017, He et al represented a method to optimize machining parameters with respect to the both environmental and economic objectives [11]. In 2018, another study is represented by Hu et al [12] to clarify the relationship between the processing sequence of a part features (PSFP) and the energy consumption of tool change and tool path during the feature transitions. They introduce a model that minimizes the energy consumption of machine tools during the feature transitions which include all the tool path and tool change operations.

Carbon Dioxide CO₂ is the most dangerous greenhouse gas in the atmosphere. Since the industrial revolution, the concentration of CO₂ rises and reaches 410 ppm (parts per million, i.e.; number of moles CO₂ per million moles of air) in June 2018 [13]. The CO₂ emissions contribute to global warming caused by the rise in temperatures and climate change [14-15]. Then, with the growing concerns on ecosystems, several intergovernmental and binding agreements are introduced to reduce the impacts of global warming. For instance,

countries adopted the Paris Agreement at the COP21 in Paris, which went into force in November of 2016 [16]. Manufacturing has an essential role that radically influences our ecosystems; thus, many researches are focused on industrial activities aiming to reduce the carbon intensity. In 2016, Liu et al also presented a numerical approach to calculate optimal cutting parameters in the aim to reduce carbon emissions and machining costs [17]. Zhang et al in 2017 proposed an optimization model for the process parameters of multi-pass dry machining to trade off process time, energy consumption and carbon emissions and then relieve the impact the environment [18]. Liu et al propose an integrated optimization model based on cutting parameters and it affect scheduling in order to reduce the completion time and the carbon emissions in machining processes [19]. In 2018, Sihag and Sangwan presented a systematic methodology to calculate the carbon emissions of CNC machine tool [20].

The optimization of the manufacturing phase can be also seen in the minimization of cutting parameters regarding different environmental impacts. In 2017, Li et al presented an integrated approach of process planning and cutting parameter optimization to minimize the total energy consumption of CNC machining based on a multi-objective simulated annealing algorithm [21]. Rajesh et al also, study cutting parameters optimization in order to reduce cutting temperature in turning based on a Genetic Algorithm at dry and MQL condition [22]. Shin et al present a new methodology in order to implement an online energy optimization environment. This methodology is used to select optimal cutting parameters [23]. Figure 1 illustrates an overall flow of the proposed methodology. In 2018, Zhou et al presented a cutting parameter optimization method for machining operations to balance carbon emissions, cutting time and cutting cost, in the part machining process [24]. One the unsustainable process is lubrication-based machining process due to the bad impact of cutting fluid on the environment. Hence, Alok and Das in 2019 present a multi-objective optimization of cutting parameters during sustainable dry hard turning [25]. Chen et al. also proposes an integrated approach of cutting tool and cutting parameter optimization to minimize the energy footprint and production time of the face milling process using a multi-objective Cuckoo Search algorithm [26].

The use of cutting fluids in machining has a very hazardous effect. It leads to health and environmental problems. Therefore, the disposal of cutting fluids must be optimized in order to respect the environment protection laws. Vegetable-based ecofriendly cutting fluids are in demand. Several researches considered vegetable-based cutting fluids as an environmentally friendly fluids and it has a better lubricating ability comparing to other fluids [27-28]. Moreover, alternative ecofriendly machining techniques such as minimum quantity

lubrication (MQL), cryogenic machining, etc. are required in order to reduce detrimental environmental effects of cutting fluids. Therefore, researchers are interested in dry machine technique. This technique uses coated tools [29] textured cutting tools [30-31], and other sustainable techniques [32]. Near-dry machining or MQL or minimum quantity cutting fluid (MQCF) represent a solution so as to hazardous environmental effects [33-37].

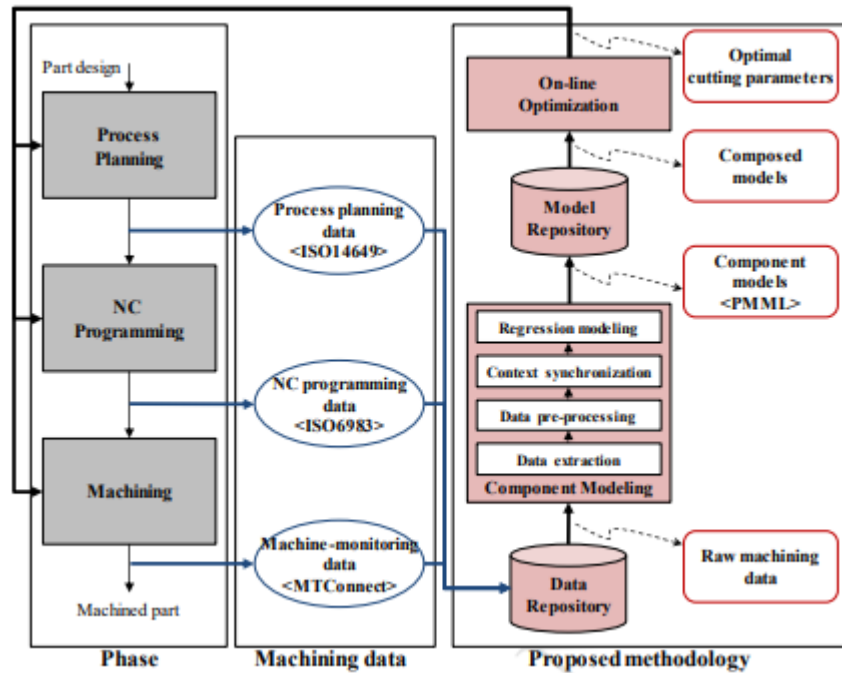


Fig 1. An overall flow of the proposed methodology by [23]

In this section, we observed from the above literature that multiple studies consider energy consumption, carbon emission and cutting fluids as an important process response. However, it is clear that in order to determine the optimal decision making, requires the knowledge of the different techniques that the designer is not an expert. Therefore, the eco-manufacturing integrating CAD is highlighted in the next section.

2.2. Eco-manufacturing integrating CAD

To increase productivity, companies are asking for improved CAD tools combining different functions such as manufacturing, cost estimation, environmental assessment, etc. Therefore, the trend in CAD systems is to integrate non-geometrical information at different levels into the purely geometrical model, such as taking into account engineering constraints and features. Bianconi et al distinguish two main areas of data exchange: horizontal (the same level of product development)

and vertical (exchanging data between systems of different levels of product development) exchange [38].

The need to analyze products in environmental terms during its design phase has led to the development of environmental impact analysis tools integrating CAD systems. Several studies, according to the literature, attempt to link these two types of software to help the designer make decisions. The history of integrating CAD systems with eco-design tools began in 1995. Among these works are methodologies [39-47], prototype tools [48-56] or commercial tools [57-60] in order to assist the non-environmental expert designer to eco-design his products.

Introduire la section suivante

3. Multi-criteria decision support methods: Overview

Multi-criteria analysis methods are decision support tools developed since the 1960s. Numerous methods are proposed to enable decision-makers to make a good «choice». Multi-criteria decision-support methods (MCDSM) are techniques that allow the integration of any type of criteria, these procedures seem to be more likely to lead to a judicious compromise rather than an often outdated optimum [61]. MCDSM are categorized into 3 categories; single synthesis approach methods, summary overridden methods and interactive methods.

- **Methods of the single criterion synthesis approach:** These approaches are used in the event that the decision-maker is able to judge any pair of actions {a, b} according to one of the following cases: either a is preferred to b, or b is preferred to a, either the decision-maker is indifferent between a and b. There is therefore no incomparability between two actions. Several methods have been developed in this decision support class, which can be mentioned: Technique for Order by Similarity to Ideal Solution (TOPSIS) [62]; Simple Multi-Attribute Rating Technique (SMART); Multiple Attribute Value Theory (MAVT) [63]; Multi Attribute Utility Theory (MAUT) [64]; Analytic Hierarchy Process (AHP) [65-67].
 - **Methods of overridden synthesis:** These approaches allow for incomparability between actions. Some are characterized by structures of preference strong, weak, indifference, incomparability. Several methods have been developed in this decision support class, which can be mentioned: Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) [68], Elimination Et Choix Traduisant la REalité (ELECTRE) [69]; Measuring Attractiveness by a Categorical Based Evaluation TecHnique (MACBETH) [70].
 - **The interactive methods:** These approaches are characterized by continuous interaction between the study man and the decision-maker throughout the decision-making process.
- reference

4. Overview of Micro/Macro-planning

The environmental impact assessment of the manufacturing process is the subject of numerous

researches. This involves reducing or avoiding processes that have an impact on ecosystems, human health, etc. In 1995, Sheng et al. and Munoz et al. analyzed the environmental impact of different waste streams [71-72]. They applied a scoring system that assesses some indicators (toxicity, carcinogenetic, irritation, flammability, and reactivity) to reduce the complexity of treatment solutions through a feature-based approach. A hierarchical parts planning strategy for environmentally friendly machining is developed in [73], where it is shown that a feature can be machined with different scenarios. The aim is to choose the most impactful machining scenario. In the work of Sheng et al in 1995, the environmental impact can be calculated at the level of each feature independently of the others (micro-planning) [74]. But, obtaining microplans does not necessarily result in a globally feasible process plan for a given part. Hence, Srinivasan et al propose another approach that considers the level of a set of features that interact (macro planning) [75]. The structure of the microplanning decision model is shown in figure 2. Sormaz and Khochonovis classify the interactions between features into the three types: Shared volume by several features, tolerance/datum dependencies or coincidental/grouping relationships [76]. In 2001, D'Souza et al., presented the microplanning, as the decomposition of machining features generated by the macroplanner into sub-features [77]. They described the implementation of a microplanner that is capable to accomplish optimally the abovementioned tasks, either minimize time or cost for 2.5-D Pocket Machining. In 2000, Tseng and Jiang proposed a methodology which analyzes the different manufacturing costs for the different feature-based machining methods, then, the one with the lowest manufacturing cost is considered as the “best” from the manufacturing point of view [78]. In 2015, Gaha et al., adopted the methodology proposed by Tseng and Jiang to evaluate the environmental impact (EI) as well as cost of a part's manufacturing process till the detail design phase [79].

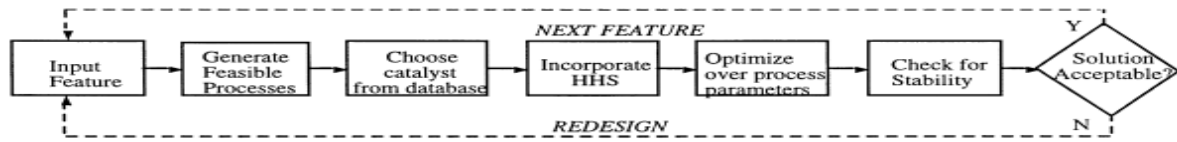


Fig 2. Schematic of the microplanning algorithm [75]

5. Proposed approach

Based on the literature review done in the previous sections, we propose our new eco-manufacturing methodology which consists in exploring both features interactions technology (FIT) and multicriteria decision support methods (MCDSM). In order to evaluate environmental impacts as well as cost, eco-design implementation must be applied [80]. We adopt this methodology in order to evaluate environmental impacts of a part manufacturing process till the CAD phase. Detailed methodology of eco-manufacturing is shown in figure 4.

The proposed methodology is realized through four levels:

- Level for input data
- Level for scenario environmental evaluation
- Level for scenario environmental selection
- Level for machining planning generator

Input data consists of feature recognition from the feature manager after the geometric modeling of our product using CAD software. Then, our methodology provides different process planning based on feature Interaction technology (FIT). The second level is to make the environmental evaluation for each possible scenario (based on the algorithm shown in figure 3). First of all, it chooses the environmental impacts to quantify using Evamix method. This method classifies the environmental impacts. In order to evaluate one EI in relation to another, two indices of dominance are calculated and then standardized and combined to provide an overall measure of dominance. Finally, an overall score per EI is calculated. Secondly, we implement LCA in eco-design using CAD/LCA integration systems to quantify the EIs for each possible scenario in an environmental impact matrix (figure 3).

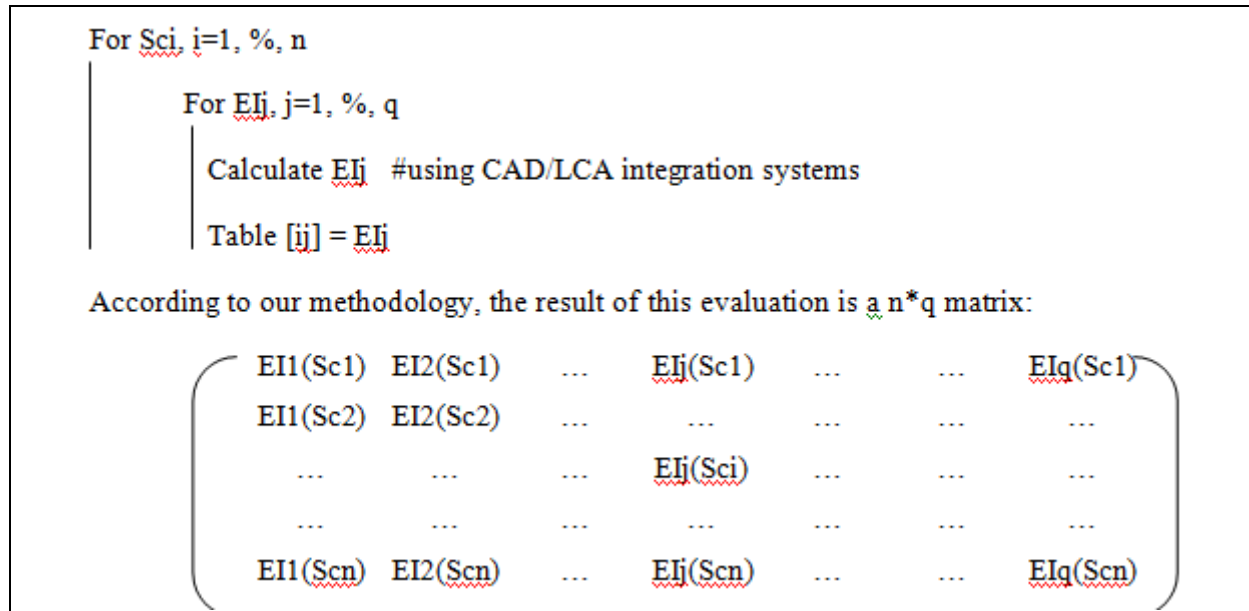


Fig 3. Environmental impact evaluation algorithm and matrix

Where; n is the total number of possible scenarios; q is the total number of EIs to quantify; i, j are two counters and $EI_j(Sci)$ is the j-th environmental impact of the i-th scenario.

After the environmental evaluation, a selection must be done in order to choose the best compromise between different environmental

impacts, i.e. the greenest scenario. Therefore, we choose PROMETHEE method to complete the comparative study of the various possible production scenarios based on equal importance for all criteria. Finally, our methodology consists of generating the machining plan related to the greenest scenario.

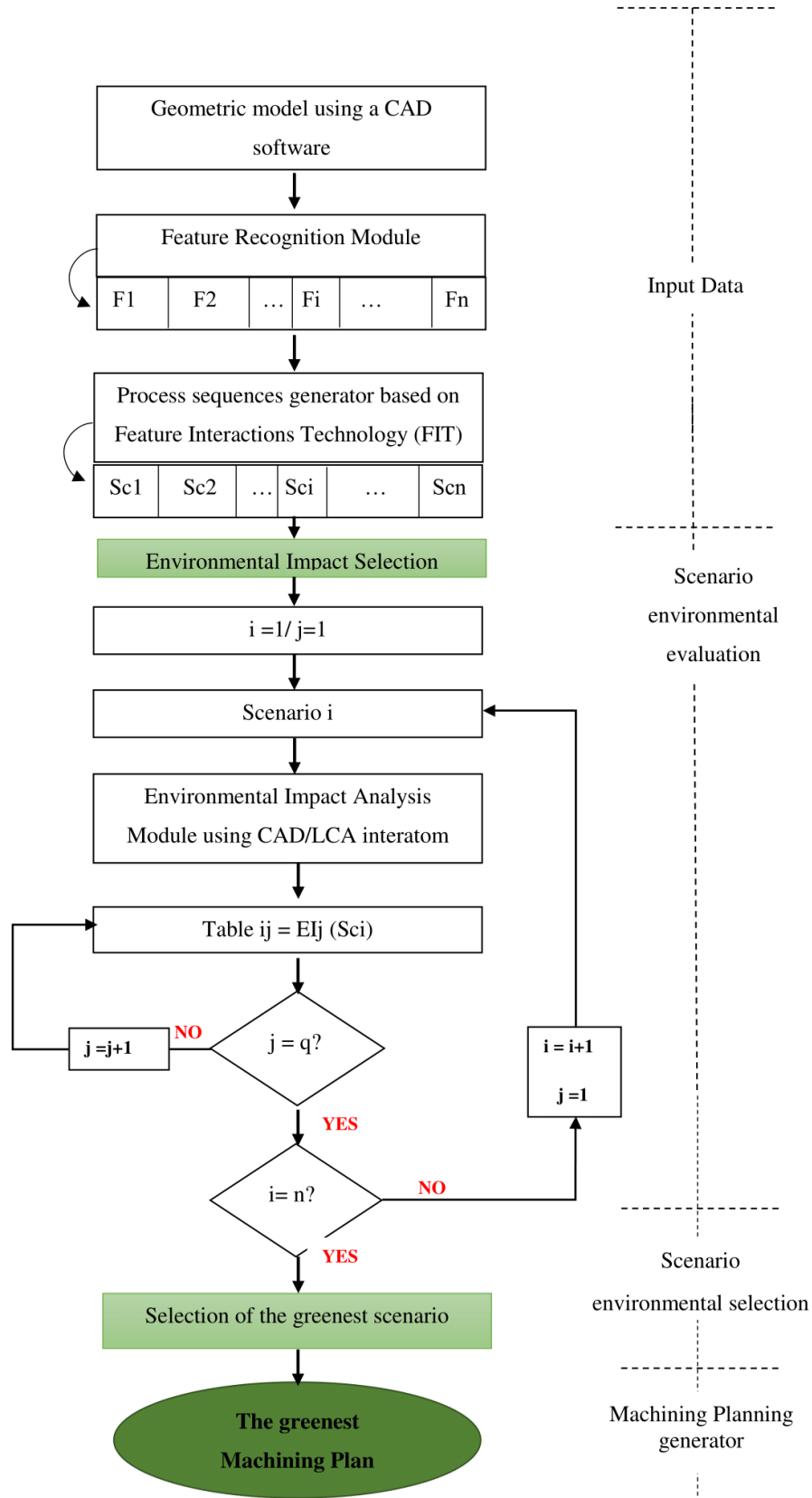


Fig 4. A new based feature-interaction eco-manufacturing methodology on CAD phase

6. Case study

To validate our methodology, we consider a sample part 100mm*60mm*10mm with three holes with increasing diameters to be drilled (Figure 5). The work piece material is assumed to be AISI 4043 alloy steel with a density equivalent to 7850 kg/m³.

Three feasible sequences with feature interaction can be considered for drilling:

- (A) 3 drills of the corresponding hole sizes are used.
- (B) The 10 mm drill is used to create a pilot hole on holes 2 and 3, then two final drills of 20 mm and 35 mm.
- (C) The 10 mm drill is used to make a pilot holes on holes 2 and 3, the 20 mm is used to make a pilot hole on hole 3 and finally a 35 mm is done.

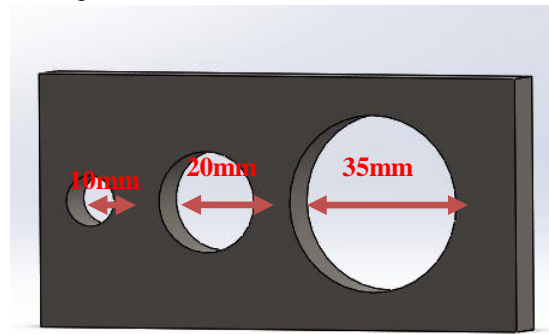


Fig 5. Case study for feature interaction

For ease of calculation, the LCA is practices with the software “Bilan Produit”, developed by ADEME [81]. The database used is developed in collaboration with EcoInvent Center and the Swiss Center for life cycle inventories [82]. By using CML method [83], 8 environmental impacts are considered [EI1= Energy consumption (MJ eq) , EI2=Resource consumption (kg Sb eq), EI3=Greenhouse effect GWP 100 mod (kg CO2

eq), EI4=Acidification (kg SO2 eq), EI5= Eutrophication (air water soil) (kg PO4 --- eq), EI6=Photochemical pollution (kg C2H4), EI7 = Aquatic ecotoxicity (kg 1,4-DB eq), EI8 = Human toxicity (kg 1,4-DB eq)]. At the scenario environmental evaluation level, a CAD/LCA integration system is used to calculate the EIs for each possible machining scenario and the process outputs are shown in figure 6.

	EI1	EI2	EI3	EI4	EI5	EI6	EI7	EI8
Sc1	5,53	2,67E-03	3,84E-01	1,33E-03	8,22E-04	1,21E-04	3,89E-01	8,64E-01
Sc2	3,29	1,59E-03	2,28E-01	7,87E-04	4,88E-04	7,18E-05	2,31E-01	5,14E-01
Sc3	2,33	1,12E-03	1,62E-01	5,59E-04	3,47E-04	5,10E-05	1,64E-01	3,64E-01

Fig.6 Case study results matrix

From figure 7 the sequence with the lowest environmental impact is C and is chosen as the best

sequence. The next stage is generating the machining plan related to this sequence.

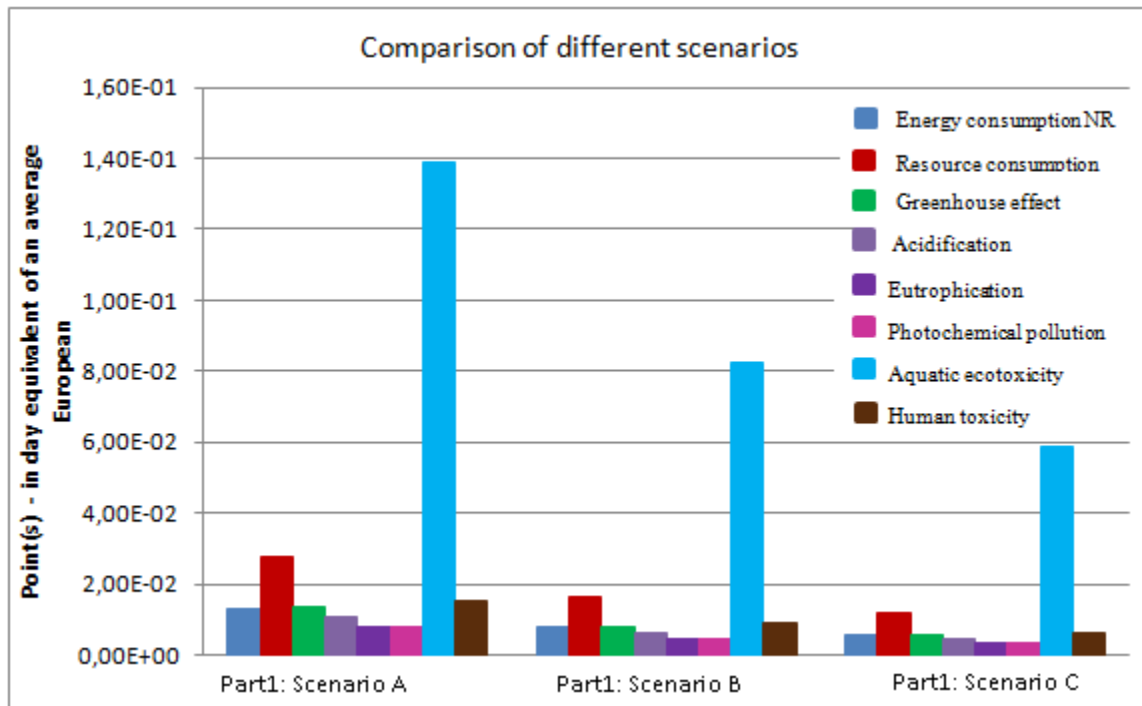


Fig 7. Comparison of different results

7. Conclusion

This paper is developed base on the work of Vukelic (2019). It presents and discusses the need for integrating environmental performances into manufacturing process based on feature interactions technology and MCDSM in order to optimize the manufacturing part process in terms of environmental impact (such as energy consumption, CO2 emission, cutting fluids, etc.) till detail design phase. A methodology for analyzing different manufacturing environmental impacts was proposed using an activity-based FIT/MCDSM model. Future works should focus on detailing the FIT-based process sequences generator and since cost constraint is a priority for manufacturers, the establishment of a methodology based on a good environment/cost compromise could attract their attentions.

8. References

- [1] European Union, 2003, Directive 2002/96/EC of the 27 January 2003 on waste electrical and electronic equipment (WEEE).
- [2] European Union, 2003, Directive 2002/95/EC of the 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.(RoHS).
- [3] European Union, 2005, Directive 2005/32/EC of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products. (EuP)
- [4] European Union, 2006, Regulation (EC) n° 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration,

Evaluation, Authorization and Restriction of Chemicals (REACH).

- [5] T. Herzog, World greenhouse gas emissions: 2005, World Resources Institute, Washington, D.C., 2009
- [6] International Energy Agency (IEA), World final consumption (2010), available at: <http://www.iea.org/Sankey/index.html#c=World&s=Final%20consumption>. Accessed on June 24, 2013. (2013).
- [7] J. Fresner. Energie-und Ressourceneffizienz in Unternehmenumsetzen, Nachhalt. Prod.2(2) (2011)58–61.
- [8] Kara S, Bogdanski G, Li W. Electricity metering and monitoring in manufacturing systems. Globalizedsolutions for sustainability in manufacturing 2011: 1-10.
- [9] Lujia Feng, Laine Mears, Cleveland Beaufort, Joerg Schulte. Energy, economy, and environment analysis and optimizationon manufacturing plant energy supply system. Energy Conversion and Management 117 (2016) 454–465.
- [10] Hu, L., Peng, C., Evans, S., Peng, T., Liu, Y., Tang, R., & Tiwari, A. (2017). Minimising the machining energy consumption of a machine tool by sequencing the features of a part. Energy, 121, 292–305.doi: 10.1016/j.energy.2017.01.039.
- [11] He, K., Tang, R., &Jin, M. (2017). Pareto fronts of machining parameters for trade-off among energy consumption, cutting force and processing time. International Journal of Production Economics, 185, 113–127.doi: 10.1016/j.ijpe.2016.12.01
- [12] Luo ke Hu , Ying Liu , Chen Peng , Wangchujun Tang , Renzhong Tang , Ashutosh Tiwari. Minimising the energy consumption of tool change and tool path of machining by sequencing the features.

- [13] <https://climate.nasa.gov/>
- [14] Gutowski, T. G. (2007). The carbon and energy intensity of manufacturing. In 40th CIRP international manufacturing systems, Seminar (pp. 1–6).
- [15] IPCC. (2007). Summary for policymakers. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden & C.E. Hanson (Eds.) *Climate change 2007: Impacts, adaptation and vulnerability, contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change*, (pp. 7–22). Cambridge, UK: Cambridge University Press
- [16] <http://www.cop21paris.org/>
- [17] Zhi-jie Liu, De-ping Sun, Cheng-xin Lin, Xiao-qian Zhao, Yun Yang. Multi-objective optimization of the operating conditions in a cutting process based on low carbon emission costs. *Journal of Cleaner Production* (2016), doi: 10.1016/j.jclepro.2016.02.087.
- [18] Zhang H, Deng Z, Fu Y, Lv L, Yan C, A process parameters optimization method of multi-pass dry milling for high efficiency, low energy and low carbon emissions, *Journal of Cleaner Production* (2017), doi: 10.1016/j.jclepro.2017.01.077
- [19] Qiong Liu, Yi Zhang, Yingdong Zhou, Integrated optimization of cutting parameters and scheduling for reducing carbon emissions, *Journal of Cleaner Production* (2017), doi: 10.1016/j.jclepro.2017.01.054
- [20] Nitesh Sihag and Kuldeep Singh Sangwan. Development of a multi-criteria optimization model for minimizing carbon emissions and processing time during machining. 25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark
- [21] Li, L., Li, C., Tang, Y., & Li, L. (2017). An integrated approach of process planning and cuttingparameter optimization for energy-aware CNC machining. *Journal of Cleaner Production*, 162, 458-473.
- [22] Rajesh, N., Yohan, M., &Venkataramaiah, P. (2017). optimization of cutting parameters for minimization of cutting temperature and surface roughness in turning of Al6061 alloy. *Materials Today: Proceedings*, 4(8), 8624-8632.
- [23] Shin S-J, Woo J, Rachuri S, Energy efficiency of milling machining: Component modeling and online optimization of cutting parameters, *Journal of Cleaner Production* (2017), doi: 10.1016/j.jclepro.2017.05.013.
- [24] Guanghui Zhou, Qi Lu, Zhongdong Xiao, Ce Zhou, Changle Tian, Cutting parameter optimization for machining operations considering carbon emissions, *Journal of Cleaner Production* (2018), doi: 10.1016/j.jclepro.2018.10.191
- [25] Alok, A., & Das, M. (2019). Multi-objective optimization of cutting parameters during sustainable dry hard turning of AISI 52100 steel with newly develop HSN2-coated carbide insert. *Measurement*, 133, 288-302.
- [26] Chen, X., Li, C., Tang, Y., Li, L., Du, Y., & Li, L. (2019). Integrated optimization of cutting tool and cutting parameters in face milling for minimizing energy footprint and production time. *Energy*.
- [27] Debnath, S., Reddy, M.M., Yi, Q.S., 2014. Environmental friendly cutting fluids and cooling techniques in machining: a review. *Journal of Cleaner Production*, 83 33–47.
- [28] Gajrani, K.K., Ravi Sankar, M., 2017. Past and current status of eco-friendly vegetable oil based metal cutting fluids. *Materials Today: Proceedings*, 4(2A) 3786–3795.
- [29] Klocke, F., Eisennblatter, G., 1999. Coated tools for metal cutting-features and applications, *CIRP Annals: Manufacturing Technology*, 48 (2) 515–525.
- [30] Gajrani, K.K., Ravi Sankar, M., 2017. State of the art on micro to nano textured cutting tools. *Materials Today: Proceedings*, 4(2A) 3776–3785.
- [31] Gajrani, K.K., Kumar Reddy, R.P., Ravi Sankar, M., 2016. Experimental comparative study of conventional, micro-textured and coated micro-textured tools during machining of hardened AISI 1040 alloy steel. *International Journal of Machining and Machinability of Materials*, 18(5/6) 522–539
- [32] Chetan, Ghosh, S., Rao, P.V., 2015. Application of sustainable techniques in metal cutting for enhanced machinability: A review. *Journal of Cleaner Production*, 100 17–34.
- [33] Dixit, D.K. Sarma, and J.P. Davim, *Environmentally Friendly Machining*, Springer, NewYork, 2012. 21.
- [34] Shaikh, V., Boubekri, N., Scharf T.W., 2014. Analyzing the effectiveness of microlubrication using a vegetable oil-based metal working fluid during end milling AISI 1018 steel. *International Journal of Manufacturing Engineering*, 2014 261349-1–261349-13.
- [35] Sharma, A.K., Tiwari, A.K., Dixit, A.R., 2016. Effects of minimum quantity lubrication (MQL) in machining processes using conventional and nanofluid based cutting fluids: A comprehensive review. *Journal of Cleaner Production*, 127 1–18. 20. U.S.
- [36] Poyner, J. R., & Simon, M. (1995). Integration of DFE tools with product development.
- [37] Roche, T. (1999). The Development of a DFE Workbench (Doctoral dissertation, Ph. D. Thesis).
- [38] OTTO, Harald E., MUELLER, Karl G., et KIMURA, Fumihiko. A framework for structured data retrieval in LCA using feature technology. In : *Environmentally Conscious Design and Inverse Manufacturing*, 2001. *Proceedings EcoDesign 2001: Second International Symposium on. IEEE*, 2001. p. 250-255.
- [39] Otto, H. E., Kimura, F., Mandorli, F., &Germani, M. (2003, December). Integration of CAD Models with LCA. In *Environmentally Conscious Design and Inverse Manufacturing*, 2003. *EcoDesign'03. 3rd International Symposium on* (pp. 155-162). IEEE.
- [40] Capelli F., Integration of LCA and Eco-Design guideline in a virtual cad framework, *The 13th edition of the CIRP International conference on Life Cycle Engineering*, Leuven, 2006

- [41] Hagström, L., & Ritzén, S. (2004). Integration of Environmental Assessment Functions in Design and Product Development Tools. *Computer-Aided Design and Applications*, 1(1-4), 33-41.
- [42] Marosky N., Challenges of data transfer between CAD and LCA software tools, 3rd International Conference on Life Cycle Management, University of Zurich at Irchel, August 2007.
- [43] Melk K., A Generic Framework for Life Cycle Applications, 3rd International Conference on Life Cycle Management, University of Zurich at Irchel, August 2007
- [44] Gaha, R., Benamara, A., Yannou, B., 2011. Influence of geometrical characteristics on ecodesigned products. *Proceedings of the International Conference on Innovative Methods in Product Design*, pp. 242–247, Venice, Italy, June 2011.
- [45] Yang, X., Li, F., Wang, X., and Wang, L. A Green-Feature Based LCA Backtracking Mechanism., *proceedings of Electronics Goes Green 2012+ (EGG)*, 2012, P1-6.
- [46] D. Russo, C. Rizzi, Structural optimization strategies to design green products, *Computer. Industry* (2014),<http://dx.doi.org/10.1016/j.compind.2013.12.009>
- [47] Hichem Hassine. Modélisation, simulation et optimisation pour l'éco-fabrication. Génie mécanique [physics.class-ph]. Ecole Centrale Paris, 2015. Français.
- [48] Takao B., Niall M. (1999), An Ecological Design Support Tool for Recyclability, Technical Reports, Industrial Electronics and Systems, Mitsubishi Laboratory, September,1999.
- [49] Pahng, KF, Senin, N, and Wallace DR (1998), "Distributed Modeling and Evaluation of Product Design Problems," *Computer-Aided Design*. 30 (6): 411-423.
- [50] Fabrice Mathieux, Lionel Roucoules, Linda Lescuyer and Daniel Brissaud. CONNECTING CAD AND PLM SYSTEMS WITH ECODESIGN SOFTWARE: CURRENT EXPERIENCES AND FUTURE OPPORTUNITIES. INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07 28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE
- [51] Cappelli, F., Citti, P., Delogu, M., and Pierini, M. (2007). Strumentoinformaticointegrato in ambiente cad per l'analisipreventivadegliimpattiambientalideiprocessi/prodotti in fase di produzione. Attidel XXXVI Convegno Nazionale AIAS.
- [52] Abad K., An ontology-based approach to integrating life cycle analysis and computer aided design, International Conference on Engineering and product design education., Université Polytechnique de Catalogne, Espagne. Septembre 2008
- [53] Jain, P. Design of an Interactive Eco-Assessment GUI tool for Computer Aided Product Design (Doctoral dissertation, Indian Institute of Technology) 2009.
- [54] Morbidoni, A., Favi, C., Mandorli, F., &Germani, M. (2012). Environmental evaluation from cradle to grave with CAD-integrated LCA tools. *Acta TechnicaCorviniensis-Bulletin of Engineering*, 5(1), 109.
- [55] Gaha, R. (2014). Eco-conception et CAO paramétrique (Doctoral dissertation, Ecole Nationale d'ingénieurs de Monastir (Tunisie)).
- [56] Chen, Z., Tao, J., & Yu, S. (2017). A feature-based CAD-LCA software integration approach for eco-design. *Procedia CIRP*, 61, 721-726.
- [57] Leibrecht, S. (2005). Fundamental Principles for CADbased Ecological Assessments (9 pp). The Inter
- [58] Solidworks, DS, Dassault Systems, "SolidWorks Sustainability, www.solidworks.com/sustainability/
- [59] Sustainable minds LLC. (2012). Connecting ecodesign with LCA for a new generation of greener products. Retrieved from www.sustainableminds.com/ecodesignand-lca
- [60] Granta Design Ltd, (2012) GRANTA CES Edupack 2012 Overview (online). Available: <http://www.grantadesign.com/download/pdf/edupack2012/2012Overview.pdf>
- [61] BEN MENA S.: «Introduction aux méthodes multicritères d'aide à la décision » *Biotechnol. Agron. Soc. Environ.* (2000).
- [62] MÉNDEZ M. GALVÁN B., SALAZAR D. GREINER D. : «Multiple-Objective Genetic Algorithm Using The Multiple Criteria Decision Making Method TOPSIS», MOPGP'06: 7th Int. Conf. on Multi-Objective Programming and Goal Programming, (2006)
- [63] Miettinen, P. and Hamalainen, R.P. (1997) 'How to benefit from decision analysis in environmental life cycle assessment (LCA)', *European Journal of Operational Research*, Vol. 102, pp.279–294.
- [64] ANANDA J. HERATH G.: « Analysis Evaluating public risk preferences in forest land-use choices using multi-attribute utility theory», *Ecological Economics* 55-408–419, 2005.
- [65] Saaty,T, (2007). Time dependent decision-making: dynamic priorities in the AHP/ANP: Generalizing from points to functions and from real to complex variables», *Mathematical and Computer Modelling* 46 -860–891, 2007
- [66] AZZABI L. AYADI D. KOBİ A. ROBLEDO C. BOUJELBENE Y. : « Une approche multicritère pour la localisation des défauts de production», conférence internationale Maîtrise et Management des Risques Industriels, M2RI, 2008
- [67] AZZABI L. AYADI D. KOBİ A. ROBLEDO C. BOUJELBENE Y. «Outils multicritère d'aide à la décision pour le diagnostic des procédés industriels », International MetrologyConference CAFMET, 2010
- [68] AYADI D. AZZABI L. KOBİ A. ROBLEDO C. CHABCHOUB H.: « Application de la méthode multicritère d'aide à la décision PROMETHEE pour le système HACCP », International MetrologyConference CAFMET, 2010
- [69] Roy, B. (1968). Classement et choix en présence de points de vue multiples. *Revue française d'informatique et de recherche opérationnelle*, 2(8), 57-75.
- [70] Bana e Costa, C. A., de Corte, J. M., & Vansnick, J. C. (2010). Macbeth (measuring attractiveness by a

categorical based evaluation technique). Wiley Encyclopedia of Operations Research and Management Science.

[71] Sheng, P., Srinivasan, M., and Kobayashi, S. (1995). Multi-objective process planning in environmentally conscious manufacturing: a feature-based approach. *CIRP Annals-Manufacturing Technology*, 44(1), 433-437.

[72] Munoz, A. A., and P. Sheng (1995). "An analytical approach for determining the environmental impact of machining processes." *Journal of Materials Processing Technology* 53.3 (1995): 736-758.

[73] Sheng, P., Srinivasan, M., and Chrysosouris, G. (1996). Hierarchical part planning strategy for environmentally conscious machining. *CIRP Annals-Manufacturing Technology*, 45(1), 455-460.

[74] Srinivasan, M., and Sheng, P. (1999). Feature-based process planning for environmentally conscious machining—Part 1: microplanning. *Robotics and Computer-Integrated Manufacturing*, 15(3), 257-270

[75] SRINIVASAN, M. et SHENG, P. Feature based process planning in environmentally conscious machining—Part 2: macroplanning. *Robotics and Computer-Integrated Manufacturing*, 1999, vol. 15, no 3, p. 271-281

[76] Dusan N. Sormaz, BehrokhKhoshnevis. Modeling of Manufacturing Feature Interactions for Automated Process Planning. *Journal of Manufacturing Systems* Vol. 19/No. 1 2000

[77] Roshan D'Souza, Paul Wright, and Carlo Skquin. Automated Microplanning for 2.5-D Pocket Machining. *Journal of Manufacturing Systems* Vol. 2a/No. 4 (2001)

[78] Tseng, Y.-J., Jiang, B.C.: Evaluating multiple feature-based machining methods using an activity-based cost analysis model. *The International Journal of Advanced Manufacturing Technology* 16(9), 617–623 (2000)

[79] Gaha, R., Benamara, A., & Yannou, B. (2015). An environmental impact/cost model for evaluating multiple feature-based machining methods. In *Design and Modeling of Mechanical Systems-II* (pp. 21-27). Springer, Cham.

[80] Vukelic, D., Agarski, B., Budak, I., Simunovic, G., Buchmeister, B., Jakovljevic, Z., & Tadic, B. (2019). ECO-DESIGN OF FIXTURES BASED ON LIFE CYCLE AND COST ASSESSMENT. *International Journal of Simulation Modelling (IJSIMM)*, 18(1).

[81] ADEME, Bilan Produit 2008, <http://www.ademe.fr/bilanproduit>

[82] Frischknecht, R., Jungbluth, N., Althaus, H. J., Doka, G., Heck, T., Hellweg, S., ... & Wernet, G. (2007). Overview and methodology. *Ecoinvent Rep*, 1

[83] Deja, M., and Siemiatkowski, M. S. (2012). Feature-based generation of machining process plans for optimised parts manufacture. *Journal of Intelligent Manufacturing*, 1-16