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Information system development for increased production process sustainability planning

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Abstract

The current era is characterized by rapid developing in all areas of society, but the most rapid expansion is in the field of science, knowledge, and technology. Galloping accessibility of the novel materials and technologies creates requirements of complex evaluation of their deployment to obtain economic and ecological sustainability. The authors of the paper present a proposal for a methodology enabling an effective decision-making process when choosing material and technological processes suitable for the manufacturing of products. This methodology was developed to enable the efficient evaluation of a wide range of materials, manufacturing technologies, including existing additive and hybrid and with focus on future and emerging technologies, too. The evaluation focuses on sustainability approach to minimize negative social and environmental impact while ensuring the required level of safety and profitability.

Keywords: Sustainability, Indicator of process sustainability, Indicator of product sustainability

1. Introduction

Last century of rapid industrialization brings totally new globally-wide environmental and social consequences. Many civilization characteristics and relationships changed in huge form and new challenges for everyday life came

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in this very short period. The consequences of development in the industrial and technical area, for example, caused - according to World Bank statistics - a major demographic milestones: in 2007, for the first time in human history, the number of the urban population exceeded the number of the rural population; at the turn of 2022/23, the number of inhabitants of our planet exceeded 8 billion; and also for the first time in history there was the phenomenon that a manufacturing workforce could consist of five generations at once. All those results in form of complicated global market correlations, depletion of natural and energy sources, uncertainty about ethical rules in new digital conditions, etc. Only humans can manipulate the Earth on such a large scale and human activities significantly contributed to the current state of the environment. Cowie (2022)

Nomenclature

i	Node group number
IF_j	Node Internal Factor selected for the evaluation
I_{ps}	Indicator of Product/Process sustainability
I_{psLCA}	*LCA* Indicator of Product/Process sustainability
LCA	Life Cycle Assessment
$_{Lj}$	indicator of LCA phase
m	number of evaluated Node Internal Factors inside of Node
n	number of evaluated Nodes
NI_i	Node indicator – indicator of the i node of the product sustainability evaluation
PMC	product manufacturing cycle

2. Sustainability

Industrial production is moving away from the previous paradigm of the priority of high profit to the paradigm of the priority of preserving the society and environment based on the knowledge of the need to establish a balance between human activities and nature. Production processes are being innovated for more efficient use of energy and natural resources. Use novel technologies or combine more technologies in one process can be very prospective for harmonization of market requirements with protection of environment and society. Peng Tao (2019)

One of the most objective approaches of the harmonization is sustainable acting. The term “sustainability” is not defined in rigid scheme. For example, definition of United Nations from 1987: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. So this is about development, it’s about development in the present which also takes into a ground what is possible in the future.” USA Department of Commerce defined sustainable manufacturing in (2009) as “the creation of manufactured products that use processes to minimize negative environmental impacts, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers” - US Department of Commerce (2009). H.A. Almeida and M.S. Correia (2016) definition connects the both above concepts to more complex dimension: ”Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, enabling fulfilment of the social, economic and other requirements of present and future generations.”

Sustainability is today widely regarded as disruption factor of doing business in digital conditions because redefines the basis of man-nature relationships. However, increasing the benefits for society and nature through sustainability creates more complex working conditions for all those who must produce and provide services sustainably. Enterprises must meet their compliance and risk management goals, they are also under pressure to develop sustainable consumer products, services, and responsible social engagement. Majstorovic (2021) and Wang (2022)

3. Research on sustainability

3.1. Previous research results

Research team of this contribution followed up on previous developments within the framework the theory of multivariate production processes (TMPP) Monka (2007), Monková (2008) and (2014).

The theory focuses on the effective sharing of information throughout the chain of cooperating entities from product design to its shipment from the production plant. The basic characteristics of this system are:

- Interconnectivity among all cooperating subjects (organizations, persons, etc.);
- Connectivity with other business information systems;
- Multi-variant process planning and production planning - the possibility of a flexible change in the production process strategy (e.g. minimizing production costs, maximizing productivity, changing the means of production, etc.);
- Necessary direct material for manufacturing evidence and optimization of incoming material variety;
- Evidence of orders and in-process of those orders;
- Evidence of workers' piecework;
- Classification of technologies;
- Reporting of technical, economical and life cycle assessment characteristics of the proposed processes;
- Optimalization of process selection.

The basic intention of previously done research and development was to increase the flexibility of all phases of preparation of the product and production process in terms of deciding on the selection of operations in production processes by evaluating economic and operation information. The most important property of the system is the possibility to prepare more strategies for product manufacturing e.g. optimized from point of view of production batch size change, minimal time consumption, maximal economic efficiency, minimal ecological impact, etc. The change from one strategy to another is very simple due to selecting an existing strategy or preparing a new strategy and storing the previous one for later use.

For the classification of information system production technologies, the DIN 8580 standard was selected in the initial stages (in 2008) of research and information system development.

3.2. Sustainability evaluation methodology development

The concept of sustainable development does focus on three aspects and nature of industrial activities in general: Profit (economic dimension), Planet (ecological dimension) and People (social dimension). Mehta (2017), Sinha (2022)

Every producer had to balance the decision-making positioning in “tetrahedron space” with nodes: Cost – Quality – Time – Flexibility in past. Every node can be understood as multidimensional room of its internal factors. However, balancing of the todays decision-making need to be made by nodes generating octahedrons or more complicated multidimensional space. Salonitis (2017)

Quazi (2023) proposed use of technical node (dimension) in sustainability evaluation, too. The node is mentioned as Technology in this research. Every additional node makes the decision process more complicated. However, the requirement of a comprehensive objective assessment of sustainability requires the inclusion of every relevant factor. The basic structure of decision-making space in frame of presented sustainability research is obtainable in table 1.

Given the complex nature of the activities from product design to end of life (Table 2), optimization in terms of economic and environmental impacts throughout the life cycle is a multi-criteria relationship with many variables. It follows that a change in any variable or criterion can cause a huge change in the outcome results. For effective modelling and optimization of the product manufacturing process, it is necessary that all tasks in marketing (target markets, LCA, kind of transport, prices), product design (material, performance, life, energy consumption, ...), transport (distances, quantities, ...) were already known and there were no changes. Any change in the product development cycle chain can have a very significant effect on the results of the product/production process optimization.

Authors developed the approach based on methodology presented by Phokane T. et al (2019) and Kadam (2016) in accordance with above-described experiences of more years lasting research and development of the TMPP information system. The currently used methodology is based on the creation of relative indicators between individual evaluated attributes (Product / Processes / Operations / Movements) in a precisely determined environment. This means that the transferability of the results to other production environments may be severely limited.

Developed methodology is applicable for:

- Marketing research methods (marked A) in Table 2;
- pre-screening methods (marked B) in Table 2;
- full-scale methods (marked C) in Table 2.

Pre-screening methods – mainly simplify Life Cycle assessment (LCA) according to Professor Ashby (2016) and developed simplify Indicator of product sustainability (IPS) are very suitable for selection the most appropriate processes/products from first proposed versions. Pre-screening methods are not time- and financially demanding and, nevertheless, have sufficient informative value for determining several of the most suitable solutions.

Table 1. Sustainability decision-making structure

Node / **Node internal factor**
1. Profit *Overall manufacturing time* *Expected profit* *Supposed cash-flow* *Market presence* *Microeconomic sustainability* *Macroeconomic sustainability* *Risk management* *Total shareholder return …*
2. People *Health & Safety* *Employment* *Contribution to regional development* *Compatibility with a political, and administrative framework …*
3. Planet *Product & Services* *Material consumption* *Energy consumption* *Contribution to climate change* *Waste generation* *Air pollution* *Water consumption and pollution* *Soil degeneration* *Land-use change …*
4. Quality *Design, Geometric accuracy, Surface finish* *Engineering* *Information* *Reliability* *Durability* *Affordability* *Maintainability …*
5. Time *Type of product* *Type & Organization of production* *Inventory level control* *Shipping Delays* *Productivity …*
6. Flexibility *Degree of digitalization* *Modularity in Products & Processes* *Changeover times* *Organizational structure & Range of plant* *Change frequency* *Speed* *Absorptive capacity* *Net output* *Adaptive human resources* *Average crew service*

Break frequency …
7. Technology *Suitable materials* *Shape & Size & Accuracy options* *Maturity level* *Performance* *Growth potential …*

Table 2. Incorporating of developed information system to the product manufacturing cycle (PMC)

<table>
<tr><td colspan="3">Internal tools of the developed IS</td></tr>
<tr><td colspan="2">External tools cooperated by IS</td><td></td></tr>
<tr><td>Stage of product life cycle</td><td></td><td></td></tr>
<tr><td>Pre-design market research
• determining the market need for the product
• determination of market required technical, economic, and environmental parameters
• forecasting of the changes in time
• company strategy vision …</td><td rowspan="7">A)</td><td></td></tr>
<tr><td>Product design
• suitable material defining
• product structure definition
• product digital model
• analyses in digital concept
• optimization of product parameters to sustainable combination…</td><td rowspan="3">B)
C)</td></tr>
<tr><td>Production process design
• Appropriate technologies selection
• Comparison of selected technologies by costs; impact on the environment and society:
    • Pre-screening method for selecting the most appropriate processes
    • Full scale methods for final process version selection.</td></tr>
<tr><td>Production
• Collection of production data
• Innovation of the processes
• Optimization of the processes</td></tr>
<tr><td>Transport to market
• Kind of transport optimization
• Distances optimization</td><td rowspan="3">B)</td></tr>
<tr><td>Product use
• Collecting information for innovating</td></tr>
<tr><td>Product disposal / recycling
• Putting to the cradle-to-cradle philosophy – circular economy run.</td></tr>
</table>

After pre-selection of the most suitable processes/products can be applied full scale methods (LCA or IPS) for detailed determination of the fulfilment of individual required factors. These analyses are then very suitable for making final decisions. The methodology basement is comparison of calculated relative Indicator of Process/Product Sustainability:

$$I_{ps} = \left(\sum_{i=1}^{n} NI_i \right) / n \tag{1}$$

Sustainability is given:

$$NI_i = \left(\sum_{j=1}^{m} IF_j \right) / m \tag{2}$$

Final calculation of Indicator of Process/Product Sustainability:

$$I_{ps} = \left(\sum_{i=1}^{n} \left(\sum_{j=1}^{m} IF_j \right) / m \right) / n \tag{3}$$

Above-described methodology can be very prospective for company/institution internal use because the described evaluation process (Table 2):

- is adapted to the natural process in companies from product development to its disposal;
- after choosing a key indicator (e.g., the amount of carbon dioxide created), needed nodes and required node internal factors (Table I) it enables a quick comparison of the created product/process variations and the selection of the most suitable ones in pre-screening (pre-selection);
- a suitably set evaluation process has sufficient informative value at optimal costs and time;
- full scale methods - comprehensively considering all essential indicators - will be used to select from a set of the most suitable solutions.

Described simplify methodology must be adopted for both purposes - possibility to compare with competitors and gaining a more objective view through generally accepted standards. The best solution for comparison with the competition companies and for objective reporting of impacts on nature and society is the use of the generally recognized ISO standard. ISO 14000 series of environmental management standards define five phases of the product life cycle:

- Material – Extraction / Ore treatment / Processing / Transportation
- Production - Material and energy transformation to product
- Transport - Product transfer to the customer
- Usage & Retail - Energy consumption / Pollutions
- Disposal - Disposal energy / Wasting / Polutions

Improving the simplify Indicator of product sustainability methodology was applied to the information system to obtain acceptable results in frame of the ISO 14000 set of standards. Scheme of coding utilized in the information system to interconnect the structure of sustainability decision-making structure (Table 1) with LCA phases is in Table 3.

		Phases of **Life Cycle Assessment** [23]					
		1 Material	**2 Production**	**3 Transport**	**4 Use**	**5 Disposal**	**6 End of Life** [3]
Nodes	**1. Profit**	11	21	31	41	51	61
	2. People	12	22	32	42	52	62
	3. Planet	13	23	33	43	53	63
	4. Quality	14	24	34	44	54	64
	5. Time	15	25	35	45	55	65
	6. Flexibility	16	26	36	46	56	66
	7. Technology	17	27	37	47	57	67

Table 3. Scheme of coding the features for simplify life cycle assessment calculation proposed by authors

By this approach is possible directly assign already calculated values of individual product/process impacts of Indicator of Product Sustainability to phases of LCA in accordance with ISO 140xx standards.

Fully LCA approach Calculation of Indicator of Process/Product Sustainability is then after adjusting the equation (3) in the form:

$$I_{ps_{LCA}} = \left(\sum_{i=1}^{n} \left(\sum_{j=1}^{m} IF_{Lj} \right) / m \right) / n \tag{4}$$

This approach is presenting LCA evaluation in form of relative indicators. In information system can be stored absolute LCA values for comprehensive LCA evaluation, of course. This approach enables high degree of flexibility in complex Product/Process data handling and presenting. The structures and procedures applied to the information system in such a way support to evaluate Product/Process the point of view of the Product Manufacturing Cycle (PMC) – in form of relative indicators – and from point of view the comprehensive LCA – in both forms - as relative and absolute LCA indicators. Possibility to select from more kinds of Product/Process evaluations make possible for user to select the most appropriate for specific conditions.

4. Sustainability methodology evaluation

The original research idea of the international team was to develop a methodology for objective comparison of novel technological processes applicable to the existing complex information system developed at Technical University of Kosice, Slovakia. Monka (2007), Monková (2008) and (2014). The requirements were for ability to evaluate economic, environmental and energy characteristics of the compared processes at the minimum.

However, the initial analysis of this research pointed to the need to implement a more comprehensive novel technological processes evaluation system with the possibility of adapting the assessment method to specific conditions:

- The implementation of the LCA methodology according to the set of ISO LCA standards was the first primary requirement of the original research assignment.
- The possibility of continuous evaluation of the product/process design throughout Product Manufacturing Cycle was the most important practical requirement.
- The possibility of synchronizing the previous two approaches in one module of the existing information system.
- Flexibility with implementation of future and emerging technologies were the second requirements of the original research assignment.
- The ability to evaluate only a selected target group – phase of LCA or stage of stage of PMC.
- The above-described ability to objectively evaluate at least from an economic, ecological and energy point of view.
- And finally, ability to create assessments in both approaches - simplify (for pre-screening/pre-selection of many variations) and full (for optimal solution selection from pre-selected variants).

5. Conclusions

The presented contribution was created in cooperation of an international team with a focus on finding effective ways to production process design (second phase of LCA) focused on additive and hybrid technologies sustainability.

This approach was applied to the information system in such a way that it is possible to evaluate both from the point of view of the Product Manufacturing Cycle and from the comprehensive LCA point of view.

Information system – based on the theory of multivariate production processes firstly at the Technical University of Košice – developed under the cooperation for practical application of process planning multicriteria optimization of processes/products and for application life cycle assessment tool with ability to evaluate sustainability of the processes/products in all crucial stages of the product manufacturing cycle and product life cycle.

The purpose of the above-described research is to create a methodology for a quick and effective decision on the suitability of the process for the specified operation through pre-selection with selected essential evaluation characteristics.

The final decision is then made by choosing from the pre-selected processes through the assessment of complex evaluation characteristics.

Authors developed and applied to the TMPP information system methodology for evaluation of process/product sustainability with basic characteristics:

- unifying philosophy and assessment environment even for very different stages of the product life cycle;
- simplicity enabling rapid achievement of repeatable results;
- optionality of evaluation complexity - simple pre-selection from a large set of possible solutions; comprehensive for a sophisticated selection from the optimal of the most suitable solutions;

- the initial sorting (pre-screening, or pre-selection) is carried out with saving time and financial resources;
- the final sorting is aimed at a comprehensive and accurate assessment of sustainability;
- modularity in that the assessment can be applied to the designated stages of the LCA or PMC and flexibility in the need to change the view point;
- flexibility allowing the narrowing or expansion of previously determined Node Internal Factors for each manufacturing node according to the specific conditions of the application.

The future research of the team focuses on the development of other hybrid and additive technologies and the use of the presented methodology for their evaluation..

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References

Almeida H.A, Correia M.S.: Sustainable Impact Evaluation of Support Structures in the Production of Extrusion-Based Parts, In: Handbook of Sustainability in Additive Manufacturing, 2016 - Volume 1, Editors: Muthu S.S., Savalani M.M., ISBN 978-981-10-0549-7, DOI 10.1007/978-981-10-0549-7

Ashby M. F et al.: Materials and Sustainable Development, 2016, Elsevier, ISBN: 978-0-08-100176-9

Cowie R.H. et al: The Sixth Mass Extinction: fact, fiction or speculation? In: Biological Reviews (2022), 97, 640-663, ISSN 1464-7931, doi: 10.1111/brv.12816

Kadam G.S., Pawade R.S.: Surface integrity and sustainability assessment in high-speed machining of Inconel 718–An eco-friendly green approach.In: Journal of Cleaner Production, 147, 273–283, ISSN: 1879-1786

Majstorovic V. et al: Digital Manufacturing in SMEs based on the Context of the Industry 4.0 framework - one approach, Procedia Manufacturing, 2021, Volume54, Page52-57, DOI10.1016/j.promfg.2021.07.009

Mehta K.: Advanced joining and welding techniques: an overview. In: Advanced manufacturing technologies. Springer International Publishing, 2017, Switzerland, pp 101–136, https://doi.org/10.1007/978-3-319-56099-1_5

P. P. Monka, K. Monková, M. Hatala, M. Janák, “Multi-variant process plan creation from view of economics and technological criteria” 2007.In: APE'2007. - Warsaw : University of Technology, ISBN 9788391623473

K. Monková, P. P. Monka, “The coding of manufacturing system objects inside the new software application”, 2008.In: Archiwum technologii maszyn i automatyzacji. Vol, 28, no. 4 (2008), p. 63-70. - ISSN 1233-9709

K. Monková, P. P. Monka, “Newly Developed Software Application for Multiple Access Process Planning”, 2014.In: Advances in Mechanical Engineering. P. 39071-39071. - ISSN 1687-8132

Phokane T. et al: Sustainability Assessment-Based Comparative Evaluation of Precision Miniature Gear Manufacturing Processes, , In: Innovations in Manufacturing for Sustainability – Editor: Gupta K., Springer, 2019, ISBN 978-3-030-03276-0, https://doi.org/10.1007/978-3-030-03276-0

Quazi, Hebab A., Shemwell, Scott M.: Title: Smart manufacturing : integrating transformational technologies for competitiveness and sustainability, First edition, Boca Raton, CRC Press, [2023] ISBN: 978-0-367-74292-8

Salonitis K.: Energy Efficiency of Metallic Powder Bed Additive Manufacturing Processes, , In: Handbook of Sustainability in Additive Manufacturing - Volume 1, Editors: Muthu S.S., Savalani M.M., ISBN 978-981-10-0606-7, DOI 10.1007/978-981-10-0606-7

Sinha P. et al: Sustainability of Large-Scale Industries in the Global Market, In: Sustainability in Industry 4.0 Challenges and Remedies, Editors: Avikal S., Singh A.R., Ram M., CRC Press, 2022, Boca Raton, ISBN: 978-0-367-60871-2

Wang, X. et al.: Non-damage deep etching of SiC by hybrid laser-high temperature chemical processing, In: International Journal of Applied Ceramics Technology, 2022, 19 / 4, ISSN 1546-542X, DOI10.1111/ijac.14061

US Department of Commerce (2009) Sustainable manufacturing initiative. In: Proceedings of the 2nd annual sustainable manufacturing summit 2009, Chicago, USA

DIN 8580 “Manufacturing processes - Terms and definitions, division”

ISO 14000 series of environmental management standards of the International Organization for Standardization (ISO)