How to cite this article:

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Title of article: „Wykorzystanie metod i systemów komputerowego wspomagania do proekologicznego projektowania rozwoju wyrobu" ("The use of methods and computer aided systems in the ecological design of product development")

Mechanik, Vol. 91, No. 1 (2018): pages 73–75

DOI: https://doi.org/10.17814/mechanik.2018.1.17

The use of methods and computer aided systems in the ecological design of product development

Wykorzystanie metod i systemów komputerowego wspomagania do proekologicznego projektowania rozwoju wyrobu

MARCIN PAPROCKI *

Presented are two concepts of the process planning design procedure and the cost estimation aided by CAPP systems. Methods aiding ecological design of the product development, such as DFMA, DFE, FMEA, QFD and LCA, are presented too. The Eco-indicator 99 method which is used in the assessment of product life cycle impact on the environment (LCIA) is discussed. The paper recommends complementing the strategic enterprise backbone with the environmental component of the product life cycle assessment (Ecological Backbone).
KEYWORDS: ecological design, CAPP, Eco-indicator 99, Life Cycle Assessment (LCA), strategic enterprise backbone

In the whole world, also in Poland, environmental protection issues are becoming more and more important. Legal regulations, directives, programs, policies, strategies as well as expectations and awareness of consumers influence the increase of pressure on the design of ecological products. An important aspect is the promotion and subsidizing of ecological products and solutions.

Concepts of designing the technological process of machining and estimating manufacture costs supported by CAPP systems

As part of the computer aided technological design systems for CAPP processing (Computer Aided Process Planning), due to the process model, three methodological approaches can be distinguished [3]:

- variant methods with determinate or partly determined pattern of process structure,
- generation methods, in which the role of the master is a set of rules and rules allowing for the construction of a process,
- semi-generational methods (hybrid) – with a general pattern in the form of a structure model.

The characteristics of methodical approaches of computer aided designing of CAPP machining are shown in fig. 1.

An important issue for enterprises is the possibility of designing the technological process of processing and estimating manufacture costs (order valuation) at the early stages of production preparation, using CAPP systems. In order to meet these needs, two concepts were proposed for designing the technological process of machining and estimating manufacture costs.

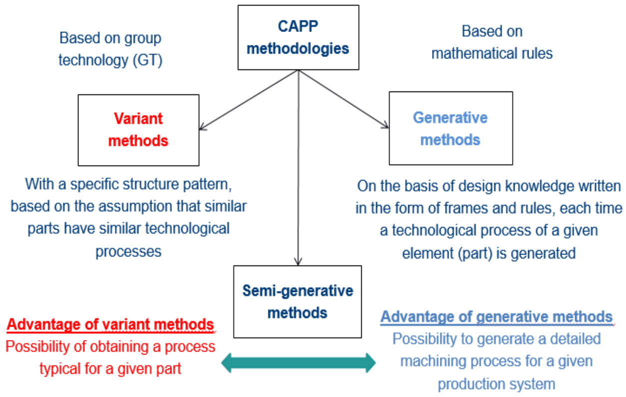

Fig. 1. Methodical approaches of computer aided technological processing design (CAPP) [7]

As part of the first concept: because searching for similar projects on the basis of the valuation process is ineffective, the use of the CAPP generation or semi-generational method to support the design of the machining process and cost estimation was shown (fig. 2).

The second concept assumes that the design of the technological processing process and the estimation of manufacturing costs is supported by a two-stage CAPP system. The variant CAPP method can be used only in the range from 30 to 90% of elements (parts) of the product [6]. Therefore, it was assumed that the next step in supporting the design of the technological processing process and estimating manufacture costs may be the application of the CAPP generation or semi-generational method (fig. 3).

Stages of computer aided pre-designing of the machining process and estimation of costs and time of part manufacture using the CAPP variant and semi-generational method are presented in the paper [7].

The use of CAPP systems to support the technological process of machining and estimating manufacture costs provides the basis for further activities carried out at subsequent stages of designing the development of the product, including: for ecological design, designing for assembly and manufacturing, and implementation of environmental life cycle assessment.

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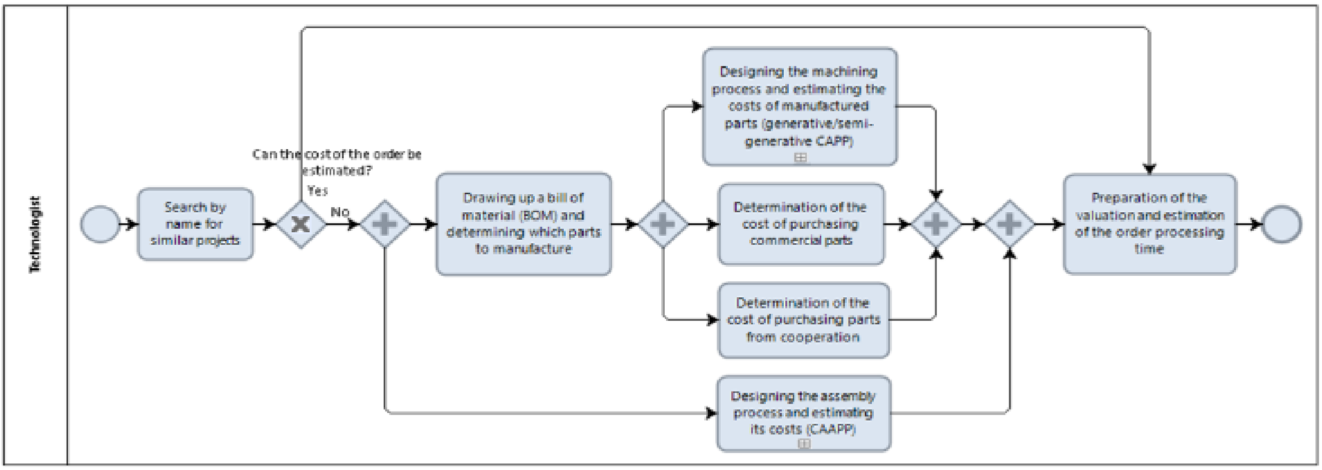

Fig. 2. Designing of the technological process and preparation of the valuation supported by the CAPP system, based on the generation or semi-generational method – I concept

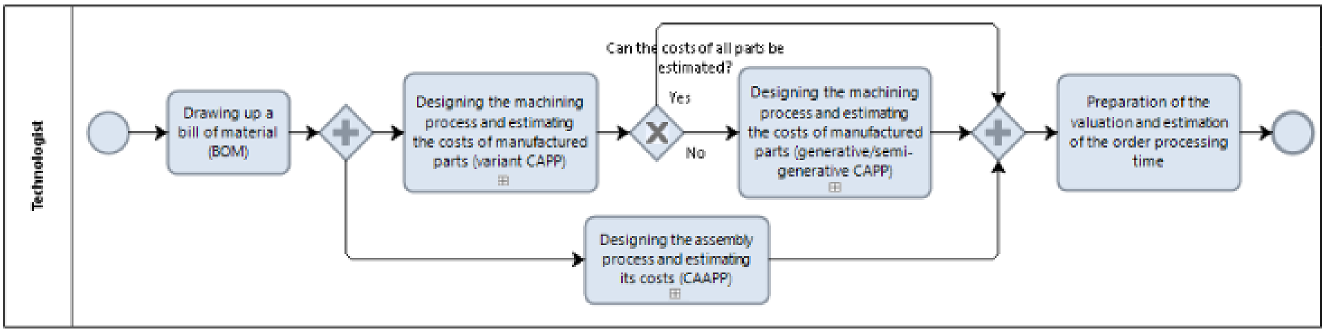

Fig. 3. Designing of the technological process and preparation of the valuation supported by the CAPP system, based on variant and generation or semi-generational methods – II concept

Methods of computer aided ecological product development design

Product design with regard to ecological aspects may be environment-oriented – DFE (Design for Environment). DFE components are, among others design methodology oriented on: ease of disassembly – DFD (Design for Disassembly), ease of recycling – DFR (Design for Recycling) and regeneration – DFR (Design for Remanufacturing).

DFE design includes all environmental aspects occurring at each stage of the product life cycle. Its aim is to minimize the negative impact of product development on the natural environment [5]. The tools that can support the ecological development of the product at early stages of design are the QFD and FMEA methods. QFD (Quality Function Deployment) is a method of developing the product quality function, which enables both the design of the quality of new products and the improvement of already existing ones, with particular consideration of the needs and requirements of customers. The FMEA method (Failure Mode and Effects Analysis) allows to predict the probability of errors, evaluate their effects and then determine the reasons for their occurrence. On this basis, preventive, leveling and corrective actions can be developed, which eliminate errors or minimize the probability of their occurrence during the design, production and use of the product.

Environmental product Life Cycle Assessment (LCA)

Environmental Life Cycle Assessment (LCA) is defined as the collection and evaluation of inputs, outputs and potential environmental influences of the product system during its life cycle [8]. The ecological evaluation of the product life cycle is carried out in four phases:

- I – determining the goal and scope of the analysis,
- II – analysis of the LCI (Life Cycle Inventory) collection of inputs and outputs,
- III – impact assessment LCIA (Life Cycle Impact Assessment),
- IV – interpretation.

LCA is associated with the development of the product and the manufacturing process (fig. 4). This method has been implemented in the form of software systems that support ecological assessment of product development in the life cycle. One of the tools used to assess the impact (LCIA) is the method of Eco-Indicator 99.

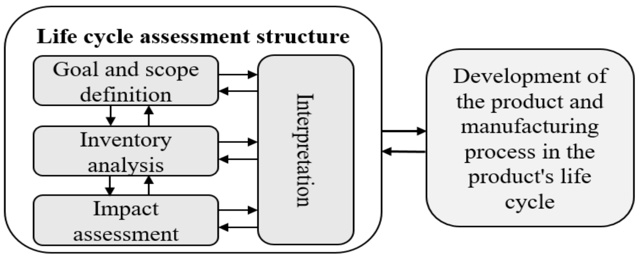

Fig. 4. Linking LCA with the development of the product and the manufacturing process [1, 8]

Within the framework of the Eco-Indicator 99 method, impact categories can be aggregated into the category of damage (fig. 5). Aggregation into three categories of damages is carried out in terms of units appearing in terms of impact, i.e. for:

- DALY (Disability Adjusted Life-Years) – the number of years of life burdened with a given disease,
- PAF (Potentially Affected Fraction) – the fraction of species exposed to a given environmental impact during the year in the area of 1 m^2,

- PDF (Potentially Disappeared Fraction) – species fractions that can potentially be exposed to a given environmental impact during the year in the area of 1 m^2,
- MJ Surplus Energy in megajoules – specifying the extra effort associated with the surplus energy that future generations will have to take to extract the same amount of resources that can now be mined at a lower cost.

Next, to obtain a single numerical result expressed in Pts (points), damage categories should be normalized and weighed (tab. I).

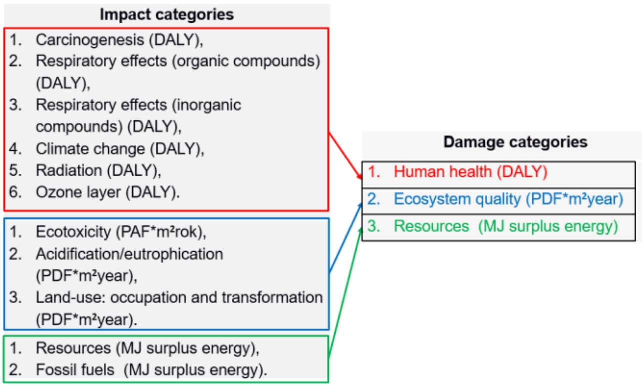

Fig. 5. Impact categories aggregated to the category of damage for impact assessment (LCIA)

TABLE I. Normalizing and weighing categories of damages (developed by [9])

Categories of damage	Normalizing	Weighing
1. Human health (DALY)	65.1	400 (Pts)
2. Ecosystem quality (PDF*m^2year)	0.000195	200 (Pts)
3. Resources (MJ surplus energy)	0.000119	200 (Pts)

Pro-ecological product design using the DFMA method

The paper [2] presents the design of the engine before redesigning using the DFMA method and after it. After redesigning, the engine's construction has been simplified. At the same time, the material of the base and lid as well as the technology of making the cover were changed. A comparison of the parameters characterizing the engine before and after the redesign is presented in the tab. II.

TABLE II. Comparison of engine parameters before and after redesign (based on [2])

	Before redesign	After redesign (DFMA)
Number of parts	19	7
Assembly duration	160 s	46 s
Cost of assembly, cents	133	38.4
Cost of parts, dollars	35.14	21.43
DFA_{index}, %	7.5	26.0

After redesigning, the engine became more eco-friendly because the number of parts and materials needed to manufacture it and the assembly significantly decreased. The answer, which variant of the engine design is the most ecological, can be obtained using the LCA method. For example, when designing a motor due to disassembly (DFD), its components should be made of the same material. This may be contradictory to the design assumption due to assembly and fabrication (DFMA), where it is aimed, among others, to change the material and manufacturing technology of the designed parts to reduce manufacturing costs.

Strategic support for projects supplemented with the component of the environmental performance assessment of the product life cycle

The concept of "strategic enterprise support" (strategic enterprise backbone) is presented in paper [4]. Strategic support of projects provides the basis for effective product development in accordance with the assumptions of Concurrent Engineering – CE and Cross Enterprise Engineering – CEE. Due to the growing importance of pro-ecological development of products, it was proposed that the strategic support of projects should be complemented with the component of the environmental assessment (environmental performance) of the product life cycle (ecological backbone) supported by LCA. Thus, this concept can be presented as a cross between components (fig. 6):

- product development management (engineering backbone) – supported by PLM (Product Lifecycle Management) systems,
- enterprise resource planning (resource backbone) – supported by the ERP system (Enter Resource Planning),
- management of cooperation with clients (costumer backbone) – supported by the CRM system (Customer Relationship Management),
- management of cooperation with suppliers (supplier backbone) – supported by the SCM system (Supply Chain Management),
- assessment of the environmental performance of the product (ecological backbone) – supported by LCA.

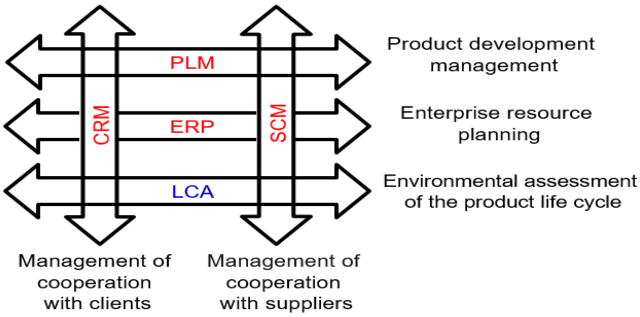

Fig. 6. Strategic support for projects supplemented with the component of the environmental performance assessment of the product life cycle

Conclusions

It is essential that the development of the product throughout the entire life cycle has the least impact on the natural environment. The use of CAPP systems to support the technological process of machining and estimating manufacture costs provides the basis for other activities carried out at subsequent stages of product development design, including related to ecological design.

An important factor improving the efficiency of eco-design development of products is the use of computer aided methods. The DFMA method can be used for ecological product development design, especially in conjunction with other methods and tools, such as: DFE (DFD, DFR – Design for Recycling, DFR – Design for Remanufacturing), FMEA, QFD, LCA and Eco-Indicator 99.

It was proposed that the strategic support of the undertakings should be supplemented with the component of the environmental assessment of the product life cycle (ecological backbone) supported by LCA.

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Translation of scientific articles, their computer composition and publishing them on the website www.mechanik.media.pl by original articles in Polish is a task financed from the funds of the Ministry of Science and Higher Education designated for dissemination of science.

Ministry of Science and Higher Education
Republic of Poland