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INTEGRATED PRODUCT DESIGN FOR THE LOWEST POSSIBLE MANUFACTURING COSTS ON A CHOSEN EXAMPLE

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Abstract: *The paper presents methodology of technical preparation for production oriented on the lowest possible manufacturing costs starting form the earliest phases of project design to the final project. The implementation of chosen computer system modules was described on the basis of created methodology. The usage of Case Based reasoning for manufacturing cost estimation in product concept design phase was also discussed.*

1. INTRODUCTION

Increasing competition among the manufacturers make them face new challenges in maintaining the high quality of their products and at the same time cutting down the costs to be cost competitive in the marketplace. These aims are difficult to achieve simultaneously because the quality of the products is closely related to higher costs. Hence for manufacturers who apply unit or small batch production costs estimation is crucial factor deciding whether they are competitive or not.

To ensure the lowest costs of the final product it is important to control them from the first stage and analyze influence of each decision according to the effect it makes on the costs.

Past studies showed that over 70% of the production cost of a product is determined during the conceptual design stage. However, the design phase itself accounts for only (6%) of the total development cost. Therefore, devoting a greater effort to design to cost is a necessary step towards optimizing product costs. Fig. 1 illustrates the percentage of product costs set and incurred in different phases. [1]

Economic evaluation as early as possible, in the design phase, is therefore essential to find the best price-function trade-off for the projects or for the product orientation. This means that early cost-estimating procedures are needed for all manufacturing processes. The designer can then make the important trade-off decisions between the various design concepts. [2]

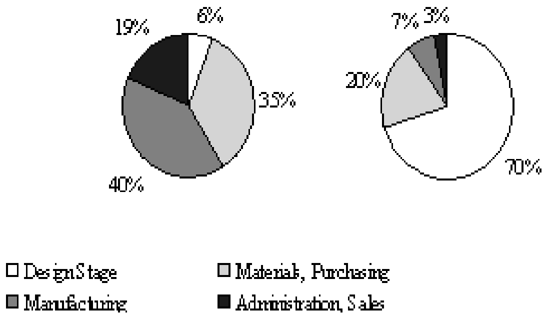


Fig.1. *Product costs set and incurred in different phases [7]*

Unfortunately, traditional cost-estimating methods are meant to be applied after all the characteristics of the product have been completely defined and its production has been planned. However, at the design stage, the problem is to estimate costs before the component has been detailed and when only a rough idea of its features is available. It is therefore necessary to implement rapid and more or less precise cost-estimation methods, depending on the available data, allowing the designer to validate one solution compared with another for economic criteria. [2]

The final technical project of a product must be designed well enough to ensure no further changes in following manufacturing stages because of their expense. Both, before the beginning and during the actual design process, the costs estimation should be carried out to enable a choice between alternative solutions while making effective financial decisions. Cost estimation at the conceptual project design stage and at product design process causes a lot of trouble mainly because of the lack of detailed information concerning material usage and the course of production process and costs generated then. So it is important for a designer, which is a specialist in the field of design but not always knows everything about cost, to have a tool which would simplify cost estimation and control at each stage of project designing.

2. THE DESCRIPTION OF METHODOLOGY OF TECHNICAL PREPARATION FOR PRODUCTION ORIENTED ON MINIMAL MANUFACTURING COSTS

The methodology is applicable to assist a designer in creating a project design of lowest possible manufacturing costs while maintaining the technical and quality requirements. Methodology implies production cost analysis at the earliest stages of designing – the conceptual study then through a development of a project and finally to a technical preparation for production. The description of methodology of technical preparation for production (TPP) oriented on minimal manufacturing costs with individual TPP stages is presented in figure 2.

2.1. Costs estimation at the conceptual design stage

At the conceptual stage when the first evaluation is made, it is often referred to as the offer evaluation. At this point there is not much information about a product available. The detailed product characteristics cannot be obtained and so the final costs are only scarcely predictable. Consequently, the designer will have to estimate the missing parameters The costs evaluation must be executed according to the existing data in which parametric method or "case based reasoning" is quite useful.

The parametric method requires creating a formula, which enables to calculate approximate production costs on the basis of given variables. The principal advantages of this method are obvious when simplicity and speed in generating results is expected. But on the other hand it is criticized because from the specifications the only results possible to obtain are different costs. Finally to the extent it shows general trends, which cannot solve particular or atypical cases.

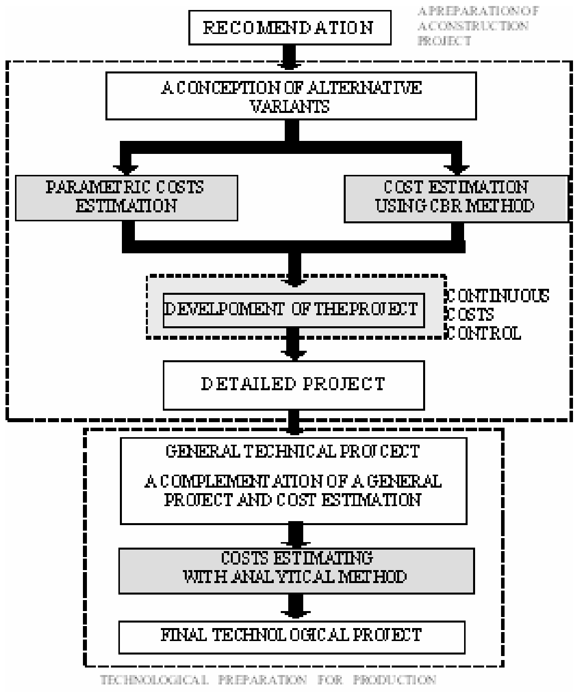


Fig.2. *Cost estimation and control at a stage of a technical preparation for production*

Another approach represents the case based reasoning, which uses solutions of past experiments to solve a new problem. It selects similar past cases and adapts their solutions to meet new particular situations.

Case based reasoning provides the ability to propose a solution very rapidly. Moreover, it functions in a transparent manner. In any time, the user knows the origin of the solutions and can correct the result. [3]

The capacity of case based reasoning to take into account unknown data is important. In this case, research will be carried out only on known parameters. The system will then propose different solutions with values for unknown data. [3]

CBR provides both a methodology for building systems and a cognitive model of how people solve problems. CBR was defined as follows: "Case-Based Reasoning is the process of solving new problems by adapting solutions that were used to solve old problems". At the highest level of generality CBR may be described as a cycle with four processes as shown in Fig.3. A CBR system retrieves a suitable case from the case library by matching indexes established for the new case (or problem case). The information and knowledge in the retrieved case is then reused to provide an initial solution to the problem. When it does not fully satisfy the problem specification the retrieved case is revised (or adapted) using domain rules, heuristics and/or human intervention. The revised case is then evaluated and criticised to assess the suitability of the solution and if suitable is retained [4].

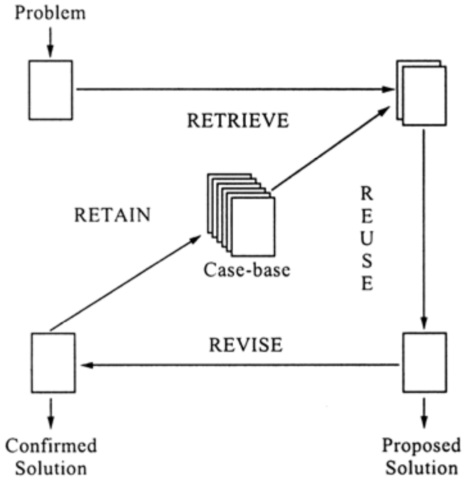


Fig.3. *The CBR cycle [4]*

2.2. Costs estimation in the process of designing

After a given draft project is accepted it is subsequently developed and detailed. At this moment there are a lot of various possibilities, which fulfill technical criteria to choose from. When a group of solutions with the technical approval is selected, the one which indicates the lowest production costs is picked. Thus in the whole process of designing it is necessary to estimate the production costs in order to take fragmentary low costs solutions, which finally comprise a complete project. The designer needs to follow, throughout the entire process of designing, adequate rules facilitating the choice of the lowest costs option.

2.3. A detailed project costs estimation

If a detailed project has been already completed, it means that all the important information is gathered to evaluate production costs. After that it is possible to employ analytic method to estimate its costs.

The analytic method allows an evaluation of the cost of a product from a decomposition of the work in elementary tasks and parts (materials). Then, the respective costs of these tasks are estimated. This method uses data from accounts department of the company. Generally, this method gives precise results; nevertheless, it needs detailed product and manufacturing process (nomenclature of the product, operative ranges, etc.) information. The use of this method therefore requires much time in order to gather all the required data. [2]

In that case to improve the process of costs estimation a group method can be used and other typical technological processes. Such estimations demonstrate small calculation error and they are comparable to the actual production costs hence they can be used as costs management and control plan regarding the entire production process and individual operations respectively.

A connection with the production process is clearly noticeable since it is vital to make a simulation of the entire production process to estimate costs using that method to present the process with its individual technological operations. Another aspect, which also needs to be estimated, is labor time and the duration of an individual technological operation. At that stage a technological plan is generated and impending errors and problems of a product project, can be identified and eliminated before they c during production phase. It is not only "design for cost" approach but also "design for manufacturing" as well.

To estimate the production costs some essential data is needed:

- a construction project,
- a technological process structure of elements and a process of assembly,
- resource requirements,
- resource rates,
- expected tasks duration,
- material requirements.

Only having these bases handy can analytic method estimation be initiated.

3. COMPUTER AIDED SYSTEM OF INTEGRETED PRODUCT DESIGN

Computer aided technical preparation to production is aimed to provide in short time information essential to make a decision. A designer who has a complete knowledge in the field of constructing needs an additional tool to verify assumed solutions and their influence on production costs. His task is to create a product which is to fulfill technical and quality requirements determined by a customer. Therefore appropriate tools are to be used which match economical aspects of adopted construction solutions.

Computer system comprises a few modules, which are used according to the amount of information available and the advance of a project design. The firs two of them relate to the stage of conception of alternative variants. One of these applies Case Based Reasoning conception to estimate costs and the other parametric method. Another module will contain a group of rules describing detailed procedures which are to be chosen during the whole design process of a product. These rules will provide information about manufacturing costs respectively to a chosen construction variants for example when a method of welding is regarded , the costs of making different kinds of weld will be indicated and then a constructor will be able to choose the one which fits technical and durability requirements and the lowest possible costs at the same time.

3.1. System environment

Presented methodology will be verified on the basis of tubular heat exchangers. The similar three-module structure is typical for each device but differs in detailed construction. The heat exchangers structure is defined by TEMA norms. According to these regulations a heat exchanger presents three parts: front end stationary head, shell, rear end head which can be a movable one. Kinds and structures of exchangers are shown on fig.4

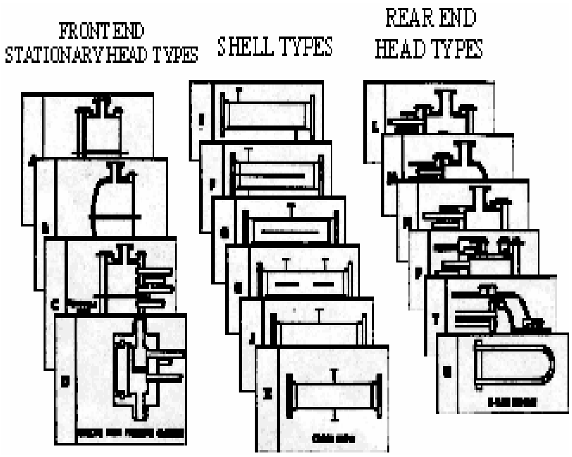


Fig. 4. *Standards of the Tubular Exchanger Manufacturers Association (TEMA)*

The implementation of methodology of technical preparation for production will result in the lowest possible manufacturing cost while maintaining the required quality of a product. Time needed for project costing will be significantly reduced which consequently considerably quicken a respond to a customer's price enquiry and allow improving a cost control in a manufacturing process.
While creating methodology of technical preparation to production and computer aided system following assumptions were taken into consideration:

- Unit and small batch production.
- Specified number of work shop.
- Possibility of technological cooperation.
- Methodology deals with economic aspect of technical preparation for production.
- Variable construction options of a product are reconsidered.
- Direct costs are analyzed.

3.2. The module aided technological preparation to production

The module of estimating labour consumption at the stage of technological preparation to production is the basis of costs estimation. The relation of production time to the costs of a single item production time enables to calculate the direct costs of labour. Analogical the direct costs of assembly are calculated and then after gathering the direct costs of all elements and the assembly as well, the direct costs of an analyzed product will appear.
When using the labour consumption module the first step is to determine a structure of an exchanger itself as it was shown on fig. 5, characterizing kinds of its comprising parts, that is the head and shield coat. Then the other comprising elements of the whole product are defined fig.6.

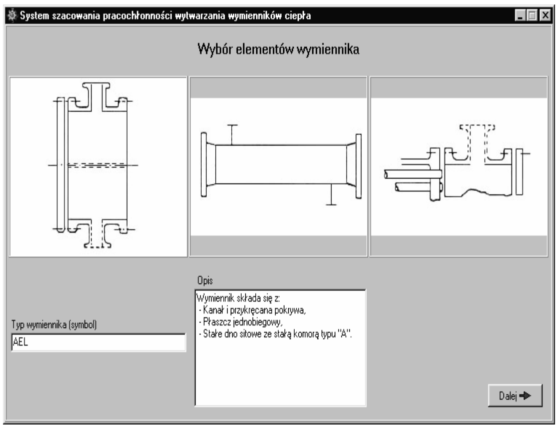


Fig.5. *Description of an exchanger structure*

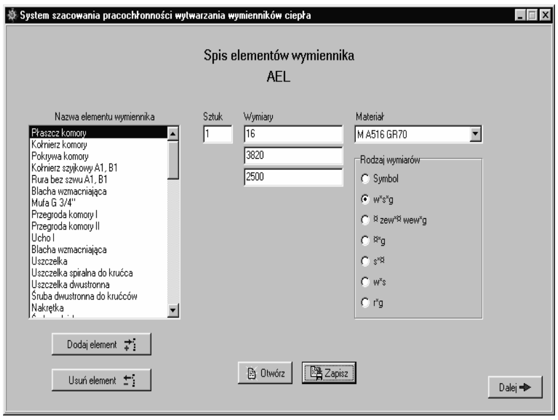


Fig.6. *Defining of product element*

A technological process is scheduled for each element. A designer describes successive parameters of processing, fig.7, but all technological time requirements are included in the program, which automatically calculates a time needed for each operation. In such a way the whole technological process is planned along with detailed processing times tj, tpz and tc. The technological process of one of the elements is shown on fig.8.

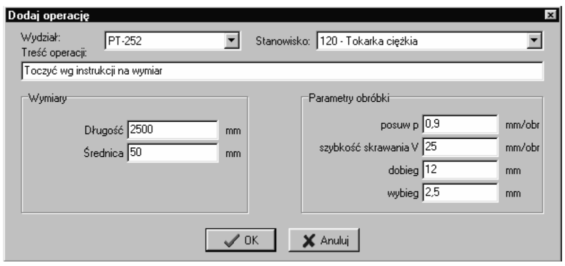


Fig.7. *The window of imputing technical parameters*

Fig.8. *A technological process of one of an exchanger's elements*

Analogically the technological processes of other elements and assembly as well, are defined. The final result of calculations is a report presenting work shop capacity and the total time of production. The exemplary statistic of production time is shown on fig.9.

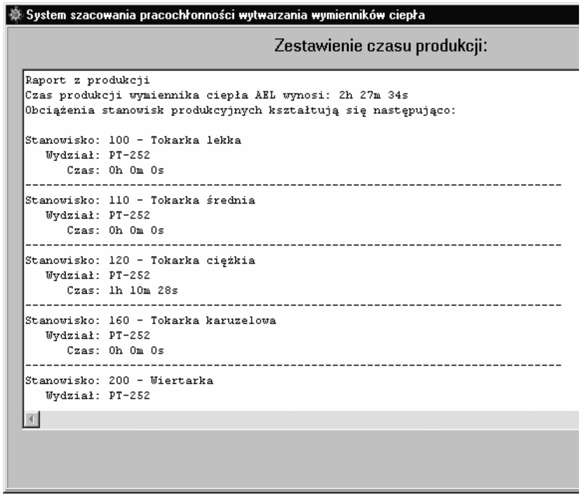


Fig.9. *A report of labour time on a chosen workshops*

In such a way a date base of production times of all the heat exchangers is build. The base stores only these production times which are later applied to calculate new projects. Because of ability to change direct labour costs, the program does not record direct costs of production. The later modules of a system will use this date to evaluate costs at the conceptual stage.

3.3. The module aided creation of an alternative variant construction with CBR approach

At a phase of creating a conception of a product the most crucial is the possibility of fast cost estimation of alternative variants. The calculations do not have to be very accurate but they should shed some light on some cost relations to enable to choose a conception of the expected lowest possible production cost. One of the approaches is a conception based on the analysis of some cases from the past (Case Based Reasoning-CBR).

The cost estimation module is one of the modules of technical methodology of preparation oriented on the lowest possible production cost, which was presented above. This module will be used at the stage of creating conceptual alternative variants construction and it will make possible to estimate and choose optimal solutions according to cost criteria. The date base of former projects is created in close relation to the results of analytical estimation of production costs at the stage of preparation to production. Date base includes following information about previous projects:

- times of production of each element and the whole product, separate for specific groups of machines, with including the assembly time,
- direct labour, material and tool costs for a separate element and the final product alike,
- material consumption and demand.

A project in a date base is presented in a tree structure, which is convenient to match not only the whole cases but groups of elements and single parts as well and decomposing cost estimation for new concepts of a product. In the case of analyzed products such as tubular heat exchangers it is possible to decompose a product into three parts: a stationary head in front, a shell and a rear end head.

Fig.10 presents a structure of cost estimation module at the phase of creating an alternative variant construction based on CBR method.

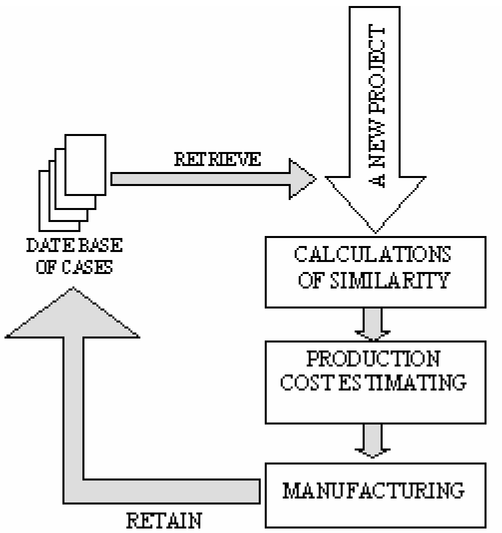
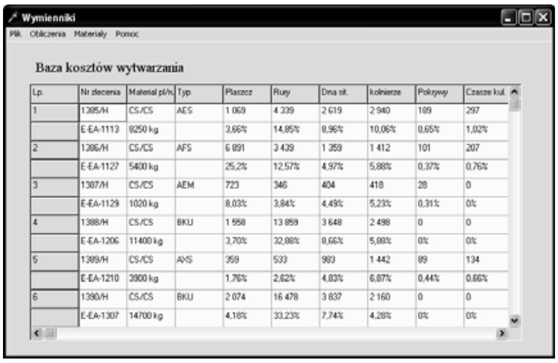


Fig.10. *A structure of cost estimation module with CBR implementation*

When costs are to be estimated and a new project is to be started, at a date base a search for the project of a similar project assumption and requirement is initiated. Among retrieved projects the one is taken which is of the closest similarity to an aim project. The information about each project is placed into date base to the future reference. Vast and up to date information about former projects collected into a date base is a priority of CBR methodology.

At the time being a date base of previous cases is collected, which would be a main source of

information in the process of cost estimation in the phase of conceptual project. The date base is shown on fig.11.
The presented module is being formed, the bases of previous cases is collected. A complete date base kept current with the latest information will be a good foundation for cost estimation of new projects. The module will acquire, according to CBR conception, mechanisms of information updating and including new ceases into date base.



Lp.	Nr zlecenia	Material pl/ru	Typ	Plaszcz	Rury	Dna sit.	kolnierze	Pokrywy	Czasze kul.
1	1385/H	CS/CS	AES	1 069	4 339	2 619	2 940	189	297
	E-EA-1113	8250 kg		3,66%	14,85%	8,96%	10,06%	0,65%	1,02%
2	1386/H	CS/CS	AFS	6 891	3 439	1 359	1 412	101	207
	E-EA-1127	5400 kg		25,2%	12,57%	4,97%	5,88%	0,37%	0,76%
3	1387/H	CS/CS	AEM	723	346	404	418	28	0
	E-EA-1129	1020 kg		8,03%	3,84%	4,49%	5,23%	0,31%	0%
4	1388/H	CS/CS	BKU	1 558	13 859	3 648	2 498	0	0
	E-EA-1206	11400 kg		3,70%	32,88%	8,66%	5,88%	0%	0%
5	1389/H	CS/CS	AXS	359	533	983	1 442	89	134
	E-EA-1210	3900 kg		1,76%	2,62%	4,83%	6,07%	0,44%	0,66%
6	1390/H	CS/CS	BKU	2 074	16 478	3 837	2 160	0	0
	E-EA-1307	14700 kg		4,18%	33,23%	7,74%	4,28%	0%	0%

Fig.11. *The date base of previous cases from the past*

4. Summary

To keep product costs as low as possible it is necessary to control them from the earliest stages of designing process. A constructor must be fully aware of economic consequences of decisions to be made. One of the crucial aspects of modern approach to designing process is design for cost [5].
Cost estimation of a product even if not precise enables a manager to make a specific offer with an exact cost estimation which convinces designers to plan costs and to reduce the amount of work required to correct a project and as a result reduces the time of releasing a product on a market and costs control as well (6).
Cost oriented design plays a significant role in cases of firms which are currently present on the market and want to obtain a fine competitive position. A designer is faced with a difficult task to choose from various possible solutions which must execute not only high technical and quality standards but the lowest possible cost of production as well. Applying adequate tools, assisting a designer, suitable to conditions in which a firm functions may be greatly profitable.
Creating of tools alone is useless if designers’ policy is not oriented on cost reduction. Case Based Reasoning approach is one of tools which facilitate quick cost estimation in a conceptual phase of a project design.

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