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EXAMINATION OF METHODOLOGY IN SELECTING MANUFACTURING PROCESS

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ABSTRACT
The process plans for mechanical products include selection of manufacturing processes: a primary process, and subsequent processes. We define primary processes as net-shape or near net-shape processes. Relation between requirements of the design, production quantity and material on one side and capability of particular process on the other side certainly exist and must be identified to be able to consider only the processes that make sense. Also production costs, quality, lead-times and ecological aspects must also be considered. The paper intention is to research and to give some guidance in classifying these requirements, to find the way how to deal with overlapping capabilities of the processes and to explore the methods of dealing with numerous data that would facilitate decisions regarding "best" process selection.
Keywords: manufacturing process, requirements, process capability, "best" process selection

1. INTRODUCTION
Manufacturing cost has prevailing influence on economic success of a product. Since up to 80% of the manufacturing and production development costs are determined by the decision made in the initial design stages [1,2,3] it is important to systematically consider all processes and process/material combinations expecting that such wider array would lead to more economic solutions. Material, process and design are closely related and cannot be taken into account separately. This means that designer's decisions must be made bearing in mind capabilities of manufacturing process and how they affect costs. Whereas designer is not a process planner he can't always foresee how his decisions can complicate manufacturing operations later in the development process. Process planner can provide him such information. Process planner is the one who can provide expert knowledge of the manufacturing operations (manufacturing tolerances, processes, procedures, limitations, scheduling and production times) to the designer. It would be very effective that the process planner as manufacturing expert would be involved in design and development process from the beginning. This approach bears elements of both concurrent engineering (simultaneous engineering) [1] and DFM (design for manufacture) [2,4,5].

2. METHODS FOR MANUFACTURING PROCESS SELECTION
Several authors proposed the procedures through which numbers of processes are reduced through several steps of "screening" according to various process attributes and product demands [2,4,5,6,7]. Initially when product is in the concept stage great number of processes and materials are considered. As product starts to get its shape and more details number of processes and materials reduces.

Applying these criterions results in optimal process selection and design that is adapted to process and material avoiding review of the part design in the advanced process planning stage.
All methods included in research have few things in common. They all give some general capability range for each process (tolerances, surface roughness, shape). Each method has its own shape classification but one thing is mutual, shapes are generally divided into round shapes, prismatic shapes and shapes that belong to neither of these two. Within this classification shapes are further divided into subclasses weather they contain features such as holes, change of section thickness. More complex shapes include threads or gears. Economical batch is given by some of them [2,3] although some give this in a very wide range which is not very useful for making quality decisions [7]. Material and process combinations are included into every method giving plain sight which combinations are out of question, but selection of material doesn't always forego process selection [4]. In order to gain final decision on process selection some authors [2,4] developed manufacturing cost estimation procedures.
Intention is to test some methods through case study and to compare the results. Figure 1. displays a part for which process selection will be carried out. Valve material is stainless steel (X45CrNi18-9; yield strength – 400MPa). The likely annual requirement is 50.000 units. Valve weight is 0,07kg. Other properties of the part can be found on the drawing (Figure 1.).

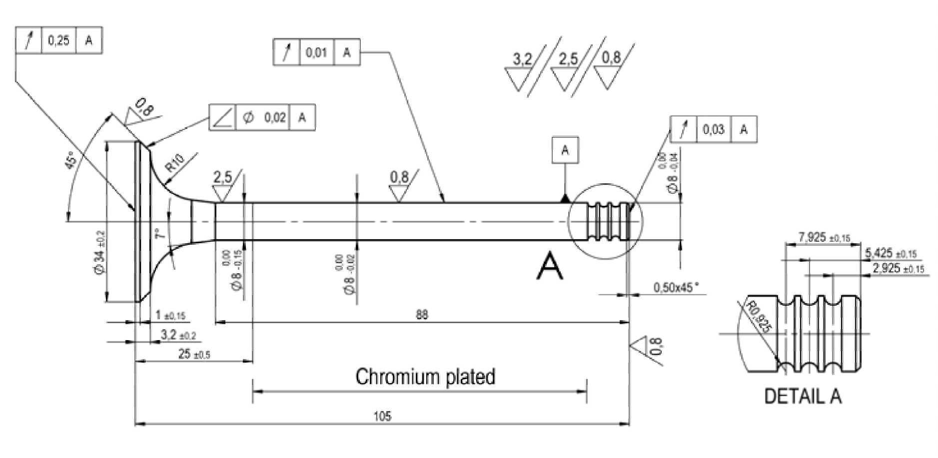

Figure 1. Air throttle valve example.

3. SELECTION STRATEGIES USING PRIMAs (PRocess Information MAps) [2]

Starting point is a table that provides information which processes are economically viable for certain combination of material and quantity. For stainless steel and batch quantity of 50.000 peaces combination a list of economically viable process is created. Process candidates are compared with product requirements and ones that don't match them are excluded from list. Figure 2. is example of process information data for shell molding. After analysis process candidates eliminated from further consideration are: centrifugal casting (shape doesn't match - circular bore remains in the finished part), shell molding (problem with parting line), ceramic mold casting (problem with parting line), drawing (simple uniform cross-section shapes), swaging (used to close tubes, produce tapering, clamping and steps in sections), powder metallurgy (maximum length to diameter ratio 4:1), electro-chemical machining (high degree of shape complexity possible, limited only by ability to produce tool shape), electro-beam machining (multiple small diameter holes, engraving), laser beam machining (for holes, profiling, scribing, engraving and trimming), chemical machining (primary used for weight reduction by producing shallow cavities).
Remaining processes: investment casting, forging, automatic machining, should be able to produce part (valve) according to requirement. It is obvious that further elimination need to be done in order to choose the optimal process. Relative component processing cost analysis for each candidate process can be done according to equation (1).

$$M_i = V_f \cdot W_C \cdot C_{mt} + \sum\left[\left(C_{mp} \cdot C_C \cdot C_S \cdot C_{ft}\right) \cdot P_C\right]. \qquad ...\ (1)$$

Where V_f is volume of finished component, W_C is waste coefficient, C_{mt} is cost of material per unit volume, C_{mp} is relative cost associated with material-process suitability, C_C is relative cost associated with component geometrical complexity, C_S is relative cost associated with size and component cross section, C_{ft} is relative cost associated with tolerance or surface finish, P_C is basic processing cost.

Economic considerations	Typical applications	Design aspects	Quality issues
Lead time several days to weeks depending on complexity and size. Material utilization high; little scrap generated. With use of gating systems several castings in a single mold possible. Resin binders cost more, but only 5 per cent as much sand used as compared to sand casting.	Small mechanical parts requiring high precision Connecting rods	Sharper corners, thinner sections, smaller projections than possible with sand casting. Cored holes greater than 13 mm. Draft angle ranging 0.25–1°, depending on section depth. Maximum section = 50 mm. Minimum section = 1.5 mm. Sizes ranging 10 g–100 kg in weight. Better for small parts less than 20 kg.	Few castings scrapped due to blowholes or pockets. Gases are able to escape through thin shells or venting. Moderate porosity and inclusions. Uniform grain structure. Surface roughness ranging 0.8–12.5 mm Ra. Allowances of ±0.25–±0.5mm should be added for dimensions across the parting line.

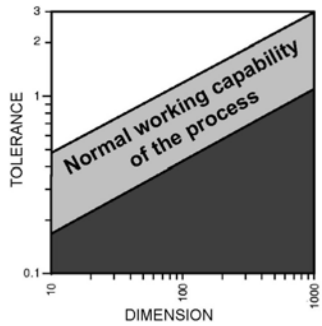

Figure 2. Shell molding process information [2].

Table 1. represents processing cost estimates of the part presented in Figure 1. which can help process planner select the optimal process and to minimize project and product costs. It is important to mention that relative cost associated with tolerance or surface finish coefficient (C_{ft}) takes into account the need of additional machining since most primary processes are not capable to achieve final tolerances and surface finishes. In this case forging turns out to be most suitable primary process due to material, design, batch quantity and other process limitations.

Table 1. Component processing costs.

Primary process	Shape complexity	Volume [mm^3]	C_{mt}	W_c	M_c	P_c	C_c	C_{mp}	Section [mm]	C_s	Tolerance [mm]	C_t	Surface finish, Ra [µm]	C_f	C_{ft}	P_c x R_c	Mi (euro-cent)
Investment casting	A1	8760	0,00377	1,0	33,03	29,2	1	1	6,1	1	0,01	4,3	0,8	1,3	4,3	125,35	158,37
Forging	A1	8760	0,00377	1,1	36,33	1,9	1	2	6,1	1,3	0,01	4,2	0,8	2,4	4,2	20,75	57,08
Automatic machining	A1	8760	0,00377	1,6	52,84	2,9	1	4	6,1	1,0	0,01	3,5	0,8	1,3	3,5	40,60	93,44

This cost estimation could be inaccurate since at this level it is not possible to determine sequence of operations positioning and work-holding [9], queuing due to failures or facility occupation, number of machines. It was shown that variants of process planning can have significant influence on production time and therefore cost of production [10].

4. SCREENING PROCESS SELECTION (USING HARD COPY DIAGRAMS) [5]

This method produces a list of processes that are able to meet design requirements. List of requirements usually consists of size, minimum section, surface area, shape, complexity, tolerances, surface roughness and material (melting point or hardness). Pair of requirements is plotted onto charts to get the search area. Processes that overlap these areas are ones that could meet design requirements. For the valve (Figure 1.) requirements are defined as: material is stainless steel (T_m = 1400 °C, ρ = 7900 kg/m^3, yield strength 400 N/mm^3), minimal section is 6,15 mm, surface area is $4{,}65 \cdot 10^{-3}$ mm^2, volume is $8{,}76 \cdot 10^{-6}$ mm^3, weight is 0,07 kg, mean precision is ±0,2 mm, roughness is 0,8 µm. Complexity of the part in this method is estimated and is given as number within the range from 1 (simple) to 5 (very complex). This may be a bit subjective rating. In our work [8] we developed an algorithm for shape complexity measure. Algorithm is still in development because it did not include data such as tolerances and surface roughness which for sure have impact on complexity of part regarding production.

For a given pair of parameters charts suggest processes that should be able to meet them. Combining results from different charts according to various parameters, as shown in Table 2., processes that do not meet all requirements are eliminated process candidates.

Table 2. Process selection results from different charts.

$t/\sqrt{A}$ - Volume	Complexity level - Size (kg)	Tolerance - Roughness	Hardness - Melting temp.
machining, cold working, hot working, electro forming, powder methods, pressure die casting, investment casting, sheet working, polymer molding, micro fabrication, gravity casting	machining, polymer molding, pressure die casting, investment casting, deformation processing, molecular methods	machining, cold deformation, pressure casting, investment casting, closed die forging, hot deformation	machining, vacuum casting, warm working, e-beam casting, powder methods, hot working, cold working, electroforming, conventional casting

Processes that appear in all chart combinations are machining, investment casting, cold working (deformation) and hot working (deformation). Selection does not include batch size, production rate and process accessibility. Also final selection must consider production costs which can be estimated according to expression (2) [5].

$$C = \text{material costs} + \frac{\text{labour cost}}{\text{batch rate}} + \frac{\text{capital cost}}{\text{batch size}}. \quad \text{... (2)}$$

Problem is that at early stage of process planning, costs are not well known to give a good estimation. Therefore further process elimination based on such cost prediction could lead to wrong decisions. It should be mentioned that Boothroyd presented equations for early cost estimation in his work [4].

5. CONCLUSION

This paper showed that design and manufacturing processes are related. Process planner planer has the responsibility to ensure that the design satisfies manufacturing process capabilities and to suggest alternatives which could reduce production costs.

The first process selection strategy is capable to give unique answer which process is optimal regarding its costs and capability, although elimination of processes in 2nd step could be a bit inaccurate regarding limited information about particular process. Second strategy of candidate process “screening” is more precise but it usually provides more than one process and further reduction is often not possible in the early stage due to lack of information.

This research investigates process selection approaches to be implemented in future work of design, material and process integration and development of our own process selection algorithm.

6. ACKNOWLEDGEMENT

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