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PRACTICAL APPLICATION OF FUZZY LOGIC IN PRODUCTION CONTROL SYSTEMS OF ENGINEER TO ORDER SMES

Abstract

In this paper the method of improving production control in engineer to order [ETO] small and medium sized enterprises is presented. Briefly, the strategy of Mass Customization [MC] and a concept of the hybrid MC-ETO production system are demonstrated. Thereafter, a method of choosing components for small batch manufacturing in advance, under conditions of single unit ETO production system, with application of fuzzy logic is described. This approach can be used in ETO companies during their transition into the hybrid MC-ETO production systems. The research was done in a collaboration with experts from the real ETO pro-duction system, in Polish SME, which manufactures mechanical parts.

1. INTRODUCTION

1.1. Theoretical background

Small and medium sized enterprises [SMEs] have ability to establish a very flexible production systems, at which a high variety of production can be successfully manage. This could be done even under conditions of the single unit, technologically challenging, prototypes manufacturing (Ruta & Zborowski, 2011). In fact, some of SMEs major in the strategy of engineering and producing unique products in response to specific order of the customer. In the literature, this strategy is called the engineer to order [ETO], and is characterized by the customer involvement in the product creation on the very beginning of value chain (Bonev, 2015). ETO production profile seems to be tailored for conditions of 21st century economy, when demand for customized products is reaching the highest level ever (Aleksic, Jankovic & Rajkovic, 2017).

One of an ETO-SMEs evolution directions could be a development in the areas of designing and manufacturing along with concept of Mass Customization [MC] (Cieśla & Gunia, 2019). The essence of MC is to provide customized products which are at the same time affordable, thus highly competitive in the market (Pine, 1993). The general foundation of MC research was the transition from a mass producer to a mass customizer, which should lead to lowering production costs and securing the long-term competitive advantage, by means of structural and process adjustments (Xu, Landon, Segonds & Zhang, 2017).

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But after the phase of systematizing MC knowledge, some of the researchers become attracted by its alternative utilization – the possibility of transition from ETO production to MC. As a result, a concept of the hybrid MC-ETO production system was introduced (Haug, Ladeby & Edwards, 2009; Mleczko, Byrdy, Cieśla & Kłaptocz, 2020). The aim of MC application in the ETO-SMEs is to lower the manufacturing costs and simultaneously maintain a sufficient level of customization. One of the most important foundation of MC-ETO, which is primary in the opinion of the author of this article, is products modularity. In this manner it is understood as a method of designing, based on combining of universal construction modules, for higher production repeatability (Mleczko, Byrdy, Cieśla & Kłaptocz, 2020). It should lead to limit the number of components, which must vary to provide the product personalization, thus effects in more stable manufacturing (Viana, Tommelein & Formoso, 2017; Cieśla & Mleczko, 2019). This approach can be used in ETO enterprises as an indicator for changes in production philosophy, switching the perspective from single unit to at least small batch flow. In the connection with management adjustments, this should lead to lowering manufacturing costs per unit. For smooth transition relevant tools will be needed in the company, to support adaptation of production control processes. However, commercial solutions often do not apply under conditions of demand uncertainty (Sobaszek & Gola, 2015), which often occurs in customized goods market. That leads to the conclusion, that dedicated approach may be needed, during transition from ETO into the hybrid MC-ETO production systems (Duchi, Tamburini, Parisi, Maghazei & Schönsleben, 2017).

1.2. Initial research and motivation

The author of this paper, for last 10 years have been investigating ETO-SMEs from metal-mechanic sector, focusing on their attempts to maximize manufacturing repeatability. In the most successful companies in this manner, the contribution of designing engineers during these activities was significant. Their managers were focused on knowledge reuse aspects as well as products reconstruction along with concept of modularity. However, when redesigning phase was well-advanced, and manufacturing could be commissioned, new challenges on the operational level were noticeable. The difficulties arose first of all from uncertainty which components and in what amounts should be produced in advance, to obtain increase in quantity of a single manufacturing batch, and simultaneously avoid long storage period. Moreover, production planning methods must be adjusted to the new circumstances, as well as workshop logistics infrastructure for in process storage and transportation. In one of the investigated enterprises, issue of choosing construction modules for production in advance left without clear answers. This almost blocked the whole evolution process. Experts from this enterprise claimed that under uncertain market conditions that they are dealing with, it is impossible to prepare unambiguous method of modules selection. They indicated that blurred forecasts and historical turnovers are the only available data for this decision-making process. The risk of error under this kind of uncertainty, which could result in freezing of the significant assets in a long-term components storage, is then too high. Thus, it was decided, to investigate the possibility of application Fuzzy logic [FL] in this problem solution, since it is suitable to describe vagueness and imprecise information (Rutkowski, 2012).

1.3. The aim of the research

The aim of this research is to investigate application of FL for the purposes of components selection to initiate in advance components manufacturing, before actual demand for them appears in a production system. It will be done on the basis of turnover statistics obtained from company's ERP system and specific knowledge of the experts. The aim is to increase manufacturing quantities in ETO-SMEs, from a single unit to at least small batch production. An essential condition for this consideration is to avoid storage of in advance components, but a short waiting time before final assembly will be acceptable due to specifics of ETO production. The research is to be carried out in Polish ETO-SME from the metal-mechanical sector, which supply high precision mechanical parts to many countries from EU as well as USA, Russia, Egypt, and others. This enterprise strives to consistently evolve with MC principles and identified a need for supporting adjusted to this transition decision-making processes. The author of this article will attempt to fill the existing research gap and broaden understanding of the practical technics of supporting hybrid MC-ETO production systems in their evolution.

2. BASICS OF FUZZY LOGIC THEORY

Research described in this article, was began with a general training, providing basic scope of FL knowledge to the company experts, that were designated for the project. In this chapter, exactly the same scope was presented, to acquaint the reader with the simplicity of the approach, which was forced with constrained number of workhours dedicated by company to the project. Moreover, well-known aspect of knowledge limitation in SMEs should be always considered, when designing methods for a real production system. The training was supplemented with practical calculation examples, which were neglected in this chapter.

The FL is employed to handle the concept of partial truth, when dealing with ambiguous phenomenon or expression. The formal description of these objects with classical set theory or bivalent logic is impossible. Typical vague impressions are “young man”, “big city”, “high temperature” (Rutkowski, 2012).

A fuzzy set A on universe (domain) X is a list of ordered pairs (Rutkowski, 2012):

$$A = \{x, \mu_A(x)\}; x \in X \tag{1}$$

where μ_A: X → [0,1] is called the membership degree (membership function), whereby 3 general situations can be distinguished:

$\mu_A(x) = 1$ means that x belongs completely to the fuzzy set,

$\mu_A(x) = 0$ means that x does not belong to the fuzzy set,

$0 < \mu_A(x) < 1$ means that x is a partial member of the fuzzy set.

The FL theory allows to map so called fuzzy relations between two or more fuzzy sets. The common method when designing fuzzy relation is intersection, when the membership of element x to set A∩B is determined as a minimum from $\mu_A(x)$ and $\mu_B(x)$ (Rutkowski, 2012).

3. THE RESEARCH

3.1. The scope of the research

The research was conducted in the enterprise which manufactures steel mechanical parts and equipment. The company employs around 50 people of which about 50% are production workers, 20% are product and process engineers and 30% are administrative, sales and logistics personnel. Approximately 15% of the company's revenue is gained from one product range, which is produced using assemble to order strategy [ATO]. Its components are manufactured in batches containing from 5 to 40 pieces. Remain 85% of revenue is gained from customized products, which are produced using ETO strategy. For last 2 years management board systematically endeavor to design unification among similar customized products by means of defining and redesigning construction modules. The aim is to establish specified products families with slightly narrower range of customization to obtain better repeatability in invoicing, designing and manufacturing. For the research described in this paper, company's management board assigned 4 experts: 1 from sales department, 1 from supply & logistics department and 2 from production department.

3.2. Plan and conduct of the research

It was assumed that the investigation should be conducted along with 5 steps plan presented on figure 1.

The first step was conducted as described in chapter 2. In the second step of investigation, experts were asked to propose fuzzy concepts, which in their opinion can be useful in qualifying components from newly designed product families for lunching in advance manufacturing. After brainstorming different ideas, discussion was initiated in order to build consensus, however problem was multidimensional and it took more than a one panel to accomplish the task. Finally, experts decided that prevailing number of ideas can be stated in two fuzzy concepts: "sufficient consumption of the component" and "sufficient universality of the component". By "universality" they understood the use of the component in multiple versions of final products which were actually manufactured.

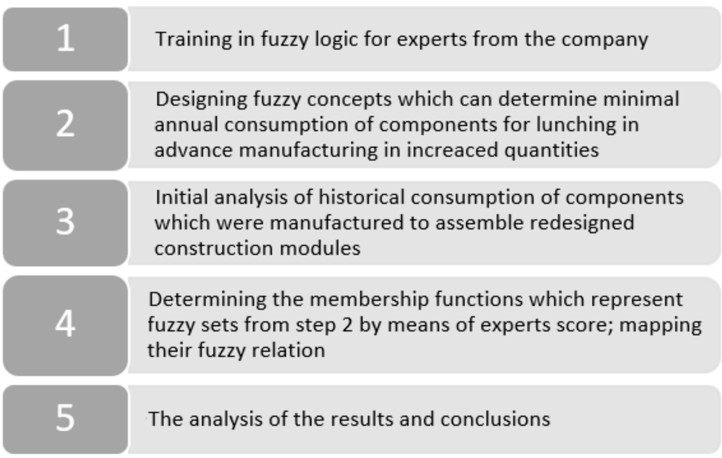

Fig. 1. Research plan

In the third step of the investigation, experts were asked to suggest sufficient period of time for initial analysis of historical consumption of components. They agreed that production of redesigned construction modules had started approximately 3 years before. Thus, it was suggested, that fuzzy concepts defined in the second step of investigation should be redefined as follows: “sufficient consumption of the component in last 36 months” and “sufficient universality of the component in last 36 months”. Experts agreed with proposal. Documentation of newly designed products (along with MC concept), as well as their components and construction modules were from the beginning distinguished with specific drawings markings. Therefore, it was possible to use unambiguous filter pattern in consumption records of company’s ERP system to identify historical turnovers. Then the time frame was narrowed to last 36 months and obtained list was exported to the spreadsheet. Using flexibility of data presentation in spreadsheet, experts where investigating consumption statistics for different components and construction modules which they expected to be representative in context of in advance manufacturing. In the end of the third step of the investigation, particular sheets with consumption statistics were printed for after meeting reflections.

In the fourth step of the investigation, experts were asked to confidentially evaluate the scores from 0 to 1 to defined in the second step of the investigation fuzzy concepts. “Sufficient consumption” and “sufficient universality” where stated in numbers from 0 to 10 for the evaluation. The results where aggregated and averaged. Thereafter 2 membership functions were determined and their fuzzy relation was mapped as presented in the subchapter 3.3.

3.3. Research findings

The values of the membership degree for designed fuzzy concepts were determined as the arithmetic mean by adding up the scores given by each of 4 experts. Determined membership functions were presented on figure 2 and figure 3. For x values greater than those presented on the figures, calculated membership degree was always square to 1.

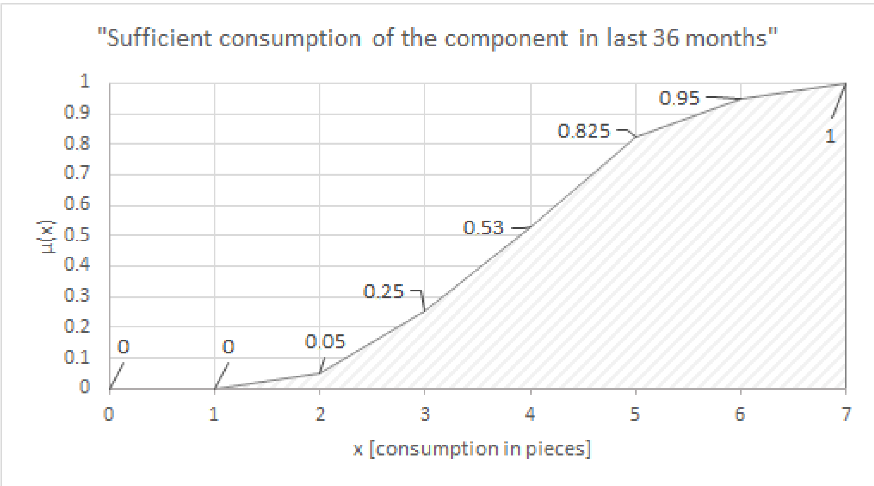

Fig. 2. Membership function of fuzzy concept “sufficient consumption of the component in last 36 months”

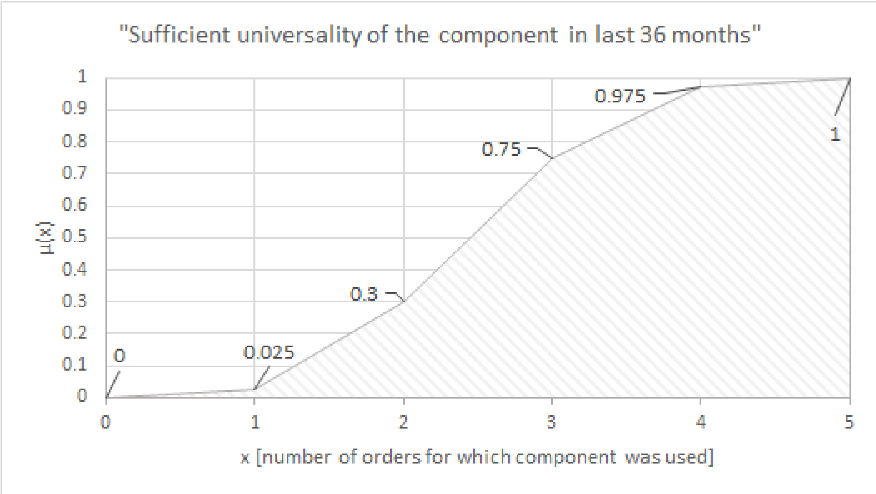

Fig. 3. Membership function of fuzzy concept "sufficient universality of the component in last 36 months"

The fuzzy relation of the investigated fuzzy concepts was mapped using the intersection method. Results were presented in table 1 and figure 4.

Tab. 1. Investigated fuzzy relation

Sufficient consumption of the component in last 36 months	**Sufficient universality of the component in last 36 months**							
	µ(x)		**0**	**0.025**	**0.3**	**0.75**	**0.975**	**1**
		pieces	**0**	**1**	**2**	**3**	**4**	**5**
	0	0	0	0	0	0	0	0
	0	1	0	0	0	0	0	0
	0.05	2	0	0.025	0.05	0.05	0.05	0.05
	0.25	3	0	0.025	0.25	0.25	0.25	0.25
	0.53	4	0	0.025	0.3	0.53	0.53	0.53
	0.825	5	0	0.025	0.3	0.75	0.825	0.825
	0.95	6	0	0.025	0.3	0.75	0.95	0.95
	1	7	0	0.025	0.3	0.75	0.975	1

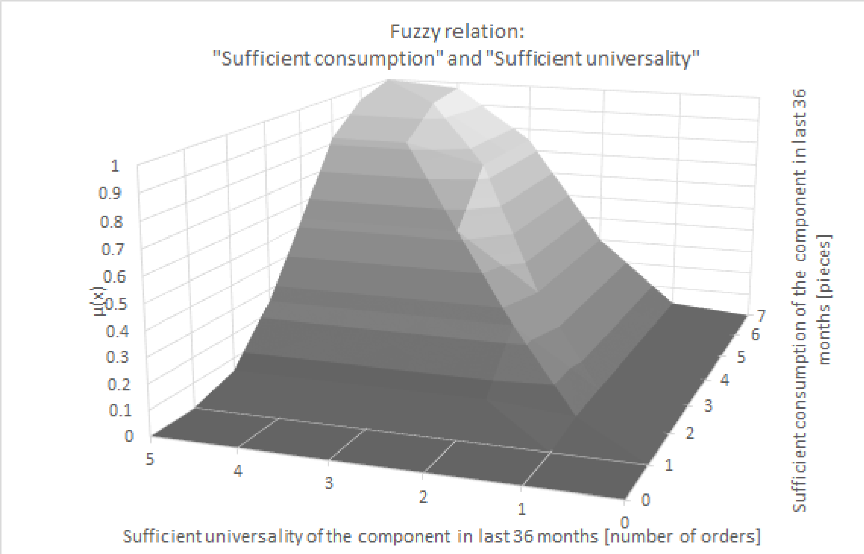

Fig. 4. Investigated fuzzy relation

3.4. Research conclusions

Research findings described in the subchapter 3.3 were presented and discussed with the experts on the last project meeting. As practitioners, they instantly proposed to calculate the membership degree for particular components, which were distinguished during initial analysis of historical consumption (step 3). On that basis, suitability of investigated fuzzy logic application for supporting production control system in the company was discussed and below findings were concluded:

- the membership degree in the mapped fuzzy relation is accurate enough to reflect the biased opinions of the experts for qualifying components or construction modules to in advance manufacturing,
- normally, under conditions of average workload in the investigating production system, in advance manufacturing could be initiated when $\mu(x) \geq 0.5$ in the fuzzy relation,
- by using the membership degree as the decision criterion for initiating in advance manufacturing, the production flow can be controlled under different levels of workload – for example $\mu(x) \geq 0.3$ can be sufficient when production system is underloaded and $\mu(x) \geq 0.9$ when it is overloaded,
- presented findings raised doubts on the part of the experts as to the score's values given in the fourth step of the investigation, but they decided not to make adjustments until the end of the first year of testing.

4. CONCLUSIONS

Experts designated to the described in this paper project showed their great involvement in work and determination to achieve relevant effects. As a result, this research has met its objective successfully and its findings will be verified by practitioners, under conditions of real ETO-SMEs production system. It should be stressed that, the designed decision criterion is a draft which needs further examination. Components and construction modules which will be selected for in advance manufacturing by means of presented method should be subject to prior manufacturing costs analysis. It should involve comparison between unit costs under conditions of existing single unit production profile and implemented in advance production in small batches. Another problem for further investigation is the moment in time of launching in advance manufacturing. For example, it can be initiated in response to actual MRP demand or temporary underloaded bottlenecks of manufacturing system. It can therefore be concluded that further research in the scope of MC-ETO and ETO-SMEs production strategies are needed to fill the current information gap. Issues presented in this paper are the part of the broader study conducted by the authors, with the purpose of designing comprehensive decision-making procedure for in advance manufacturing, under conditions of ETO-SMEs production systems.

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