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ROUTING FLEXIBILITY ANALYSIS OF DIDACTIC FLEXIBLE MANUFACTURING CELLS USING EVIDENCE NETWORKS

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A B S T R A C T

Flexible manufacturing systems are becoming increasingly popular in modern industry, providing flexibility in producing different products and quick adaptability to changes in the production program. Didactic FMC (DFMC) are small manufacturing systems used for educational purposes, providing students with practical experience in production. DFMC systems are the basic element in learning new concepts of Industry 4.0. This paper explores the flexibility of routing components in DFMC systems using the Dempster-Shafer theory of belief functions and evidence networks developed based on this theory. By using the Dempster-Shafer theory, we evaluate the flexibility of routing in the system for producing different products, i.e., the system's ability to adapt to changes in the production program according to the concepts of Industry 4.0. The analysis of routing flexibility allows for identifying critical points of the system and suggestions for improving system efficiency. The results show that routing flexibility is a key factor for the efficiency of the DFMC system. The Dempster-Shafer theory provides a precise analysis of beliefs based on various input parameters, which contributes to the precision and reliability of the analysis of routing flexibility of DFMC system components. This paper contributes to the understanding of routing flexibility and provides guidelines for further research in this area.

1. INTRODUCTION

Flexible manufacturing systems are becoming increasingly popular in modern industry, providing flexibility in producing different products and quick adaptability to changes in the production program.

Didactic FMC (DFMC) are small manufacturing systems used for educational purposes, providing students with practical experience in production. DFMC systems are the basic element in learning new concepts of Industry 4.0 (Browne et al., 1984, Mirkov, 2022).

This paper explores the flexibility of routing components in DFMC systems using the Dempster-Shafer theory of belief functions and evidence networks developed based on this theory. By using the Dempster-Shafer theory, we evaluate the flexibility of routing in the system for producing different products, i.e., the system's ability to adapt to changes in the production program according to the concepts of Industry 4.0. The analysis of routing flexibility allows for identifying critical points of the system and suggestions for improving system efficiency (Gupta & Goyal 1989).

The results show that routing flexibility is a key factor for the efficiency of the DFMC system. The Dempster-Shafer theory provides a precise analysis of beliefs based on various input parameters, which contributes to

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the precision and reliability of the analysis of routing flexibility of DFMC system components.

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2. DEMPSTER-SHAFER THEORY OF BELIEF FUNCTIONS

Making conclusions (reasoning) about certain situations from the real world is often in difficult circumstances with insufficient knowledge, no clearly defined criteria, and mutual antagonism. Information about evidence can come from different resources: based on a person's experience, from signals recorded by appropriate sensors, from the contents (the context) of published papers and so on. Such evidence is rarely clearly delimited; it's often incomplete, ambiguous in its meaning and full of flaws. Dempster-Shafer belief function theory provides powerful tools for mathematical presentation of the subjective (opposite of what probability theory is based on) uncertainty while it relies mainly on the possibility of explicit definition of ignorance (Shafer, 1976). This theory is intuitively adapted formalism for reasoning below uncertainty limit. It, actually, represents the generalization of Bayesian theory of conditional probability (Oaksford & Chater, 2009). As such, it provides formally consistent method for interpretation and connection of evidence, which inside itself carries some degree of uncertainty, and in addition, provides getting meaningful answers to posed questions using only partial evidence. Complete records can be used only in necessary cases.

2.1 The Basic Concepts of Belief Functions

Model of the belief function consists of variables, their values and the evidence, which supports the value of variables. Variables represent specific questions regarding the aspect of the problem under consideration. Given questions are answered using data originating from various sources, i.e., from context of published papers, from measurement data, from expert opinions, etc. Fully integrated support to the sought answer is called evidence. Evidence can be represented by belief functions, which are defined as follows: Definition.1. (Shafer, 1976) Let Θ be a finite nonempty set called the frame of discernment, or simply the frame. Mapping Bel: 2Θ → [0,1] is called the (unnormalized) belief function if and only if a basic belief assignment (bba) m: 2Θ → [0,1] exists, such that:.

$$\sum_{A \subset \Theta} m(A) = 1 \quad (1)$$

$$Bel(A) = \sum_{B \subset A, B \neq \emptyset} m(B) \quad (2)$$

$$Bel(\emptyset) = 0 \quad (3)$$

Expression m(A) can be viewed as the measure of belief which corresponds to subset A and takes values from this set. Condition (1) means that one's entire belief, supported by evidence, can take the maximum value 1, and condition (3) refers to the fact that one's belief, corresponding to an empty set, must be equal to 0. Value Bel(A) represents the overall belief corresponding to the set A and all of its subsets. Each subset A such that m(A) > 0 is called a focal element. The empty belief function is the function which satisfies m(Θ) = 1, and m(A) = 0 for all subsets of A ≠ Θ. This function represents total ignorance about the problem under consideration.

2.2 What are the Evidential Systems?

Valuation Based Systems (VBS) is an abstract framework proposed by Shenoy (Shenoy, 1992; Đapić et al., 2016) for representing and reasoning on the basis of uncertainty. It allows representation of uncertain knowledge in various domains, including Bayes' probability theory, Dempster-Shafer's theory of evidence which is based on belief functions, and Zadeh-Dubais-Prad theory of possibility. Graphically presented VBS is called a valuation network.

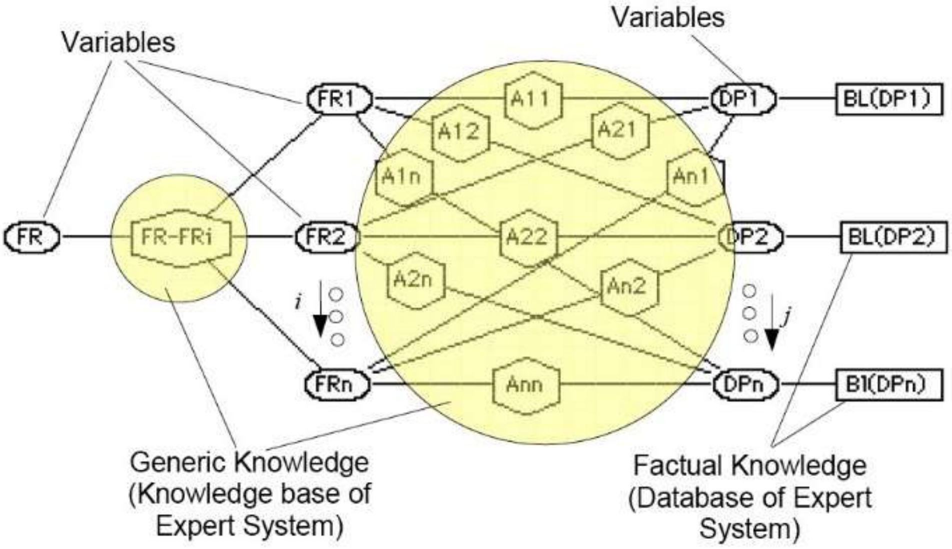


Figure 1. The concept of evidential networks (Đapić et al., 2016)

VBS consists of set of variables and set of valuations that are defined on the subsets of these variables. Set of all variables is denoted by U and represents a space covered with problem which is under consideration (Jiroušek & Shenoy, 2014). Each variable represents a relevant aspect of a problem. For each variable Xi will be used ΘXi to denote the set of possible values of variable s called the frame of Xi. For a subset A (|A| > 1) of U, set of valuations that are defined over ΘA represents the relationship between variables in A. Frame ΘA is a direct (Cartesian) product of all ΘXi for Xi in A. The elements ΘA are called configurations of A. Knowledge presented in this type of valuations is called generic or general knowledge (Fig. 1), which can be represented as a knowledge base in expert systems. The VBS also defines valuations on individual variables, which represents so-called factual knowledge, and it constitutes database in expert systems (Figure 1). For a problem, general-generic knowledge defines an expert. During reasoning process that knowledge won't be modified. Factual knowledge will vary in accordance with condition of a problem currently being under consideration. The VBS treats on the same way these two kinds of knowledge. The VBS systems suited for processing uncertain knowledge described by functions of belief function theory are called Evidential Reasoning Systems or Evidential Systems, and valuation networks are now called evidential networks (EN) Qiu et al. 2018 (Figure 1). The objective of reasoning based on the evidence is an assessment of a hypothesis, in case when the actual evidence is given (the facts). This can be accomplished by evaluating valuation networks in two steps (Đapić et al., 2016): Combining all belief functions in evidential network, resulting in a so-called global belief function; Marginalization of global belief functions in the framework of each individual variable or subsets of variables produces marginalized values for each variable or subset of variables (Aguirre et al., 2013). Easily way of understanding the reasoning process and its graphical interpretation is the condition on which depends whether and how fast these systems will be applied in solving everyday problems. As a software support to the VBS systems application, several software tools have been developed. For evidential systems the very known are: McEvidence, Pulcinella and DELIEF. McEvidence is an application that was developed for reasoning under conditions of uncertainty (Figure 3). Using this system the user can create a graphical network of variables, their relationship and to bring in any records related to the variables. When all available input records that reflect current system status or process under analysis are being entered, evaluation of network can start. During evaluation process first the global belief function is being generated by applying combining operation and then afterwards the marginalized values of all variables are being calculated.

3. FLEXIBILITY OF ROUTING IN DFMC

Flexibility is defined as the ability of a technological system to cope with variable circumstances (Buzacott & Mandelbaum, 1985) or instability caused by the environment (Mascarenhas, 1981). Flexibility is one of the key objectives of any technological system and a critical measure of overall production performance. From the theoretical postulations of the characteristics of FMC according to Lim (1986), Yilmaz and Davis (1987), flexibility is determined by eight categories of flexibility: Machine Flexibility, Process Flexibility, Product Flexibility, Routing Flexibility, Volume Flexibility, Process Sequence Flexibility, and Production Flexibility. Routing flexibility can be defined as the ability of a technological system to cope with failures and continue producing a given set of parts. This ability exists if a particular type of part can be processed through several routes, or equivalently, if each operation can be performed on multiple machines

(Goyal & Bengio, 2022). The main applicable circumstances arise when a system component, such as a machine tool, breaks down. This flexibility can be measured by the robustness of the FMS when there are failures, and production continues in changed circumstances. This flexibility can be achieved by allowing automated and automatic redirection of parts to other machines, which also enables redundancy of machine tools; as well as duplicating the assignment of operations. Monitoring systems or tracking networks can be a powerful tool in determining routing flexibility, i.e., determining the optimal grouping of parts for processing in a didactic flexible cell (DFMC). By varying different geometric shapes that can be found in the educational process, i.e., students' exercises, the characteristics of DFMC that we want to present to students can be emphasized. In the example we are analyzing, we want to examine Routing Flexibility for two given conceptual solutions of DFMC. Routing flexibility in FMC refers to the ability of the production process to change depending on production needs. This flexibility allows production processes to be optimized for different types of products, reduce waiting times, and increase overall productivity. Specifically, as previously mentioned, routing flexibility allows FMC to adapt to different production tasks and changes in production without the need for manual intervention. For example, if a machine breaks down or there is a production interruption, routing flexibility allows the production process to be redirected to other machines in the FMC to avoid loss of time and resources. Additionally, routing flexibility allows FMC to adapt to different production quantities and needs. Calculating routing flexibility for FMC usually involves analyzing different possible routes through the manufacturing system, taking into account various factors such as machine availability, production time, maintenance needs, and the like (Godinho Filho et al., 2014). One way to calculate routing flexibility in FMC is to use production process optimization algorithms. These algorithms consider various optimization criteria such as production time, production costs, or maximizing production capacity (Iqbal et al., 2014). Another way to calculate routing flexibility in FMC is to use simulation modeling. Simulation modeling allows for the analysis of different production scenarios, taking into account different conditions and parameters, in order to assess the performance and flexibility of the FMC. In both cases, calculating routing flexibility in FMC is a complex process that depends on many factors and requires expertise and experience in manufacturing engineering and automation (Mahdavi et al., 2009). The available example being analyzed involves two concepts of DFMC. The common characteristic of both DFMCs relates to the following identical components: a robot with a peripheral axis, a CNC milling machine, programmable and gravitational feeders, and a type of control system (robot controller and machine control unit). The difference relates to the CNC lathe. The first DFMC has a standard (classical) type of turret head, and the designation DFMC1 is introduced for this flexible cell. The second flexible cell has a turret head with driven tools that allow the CNC lathe to perform smaller milling operations, which gives it the ability to process parts from group two according to the part categorization in Table 2 on a single type of machine; i.e., a CNC turning center. The designation DFMC2 is introduced for this type of flexible cell in further analysis. In the analysis of Roughing Flexibility, evidence systems for the established part groupings have two clear goals. The first concerns the display of the ability of evidence networks to absorb knowledge that has been accumulated over the years in production engineering. The second goal relates to the expansion of previously generated evidence networks and their use as an auxiliary tool in the decision-making process. These goals will be achieved through an example that relates to the selection of part structures for processing a hypothetical group. This type of part has already been used in other types of exercises (e.g., designing a technological process for CNC machines), so students have some experience. As a result of the analysis, different classes of surfaces were identified on all parts (Figure 2). Types of processed surfaces include primary rotational (PR), secondary planar external (SPo), secondary planar internal (SPi), primary planar (PP), secondary rotational (SR), etc. Primary surfaces give parts their general shape. Secondary surfaces, such as planar internal and external surfaces and auxiliary holes, are processed from primary surfaces. The division of surfaces into primary and secondary was not made based on functional importance or processing complexity. Based on the classification of hypothetical surfaces, parts are divided into five categories, as shown in Table 1.

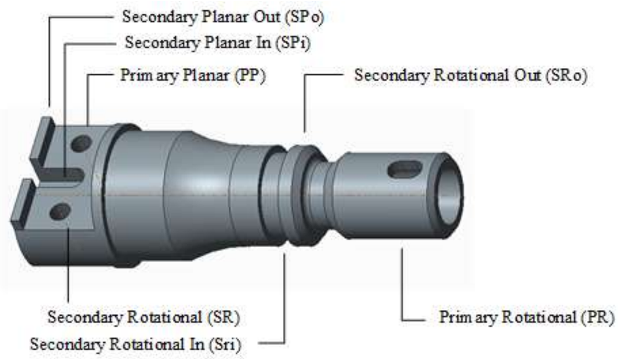


Figure 2 . Different classes of surfaces

The classification of all parts into five categories was based on the combination of these surfaces, and is shown in Table 1. Accordingly, using the corresponding statistical analyses in Table 2, we form the percentage of the use of different processing machines or types of mechanical operations for processing each category of parts. These percentage ratios are also valid for the total number of operations for final processing. Thus, in the first category of parts, 100% of the work is represented by groove milling, while in the second category of parts, 75% is attributed to milling and 25% to drilling.

It is important to note that the level of reliability of the data in Table 2 cannot be taken as 100%. By default, in the following analysis, we will assume that the level of reliability in the accuracy of this data is 95%. This means that the results of the analysis that was prepared (in the case considered by the lecturer) can be considered accurate with a probability of 0.95.
The rest of this paper shows how to apply the generated knowledge in conceptual design. The theory of belief functions together with proof systems or evidential networks allowed for the presentation of this knowledge in an appropriate form and later use as an aid in the decision-making process. The group of lecturers analyzed their exercise program and decided to adapt it to students in such a way that the flexibility of routing in DFMC is better demonstrated by choosing an adequate group of parts. The percentage share of these partswith corresponding belief functions is shown in Table 3 for one of the variations presented in Table 5.

Table 1. Categorization of parts in school examples of exercises

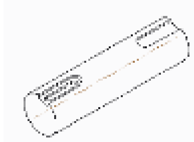
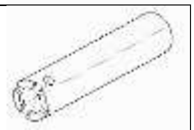
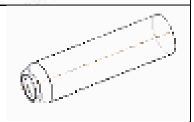
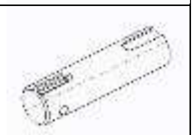
	Categorization of parts in schoole xamples of exercises	**Example sketch**
1.	Secondary Planar In (SPi)	
2.	Secondary Planar Out + Secondary Rotational (SPi+SR)	
3.	Secondary Rotational Out + Secondary Planar In (SRo+SPi)	
4.	Secondary Rotational Out + Secondary Planar In + Secondary Rotational (SRo+Spi+SR)	
5.	Secondary Rotational Out + Secondary Rotational In + Secondary Planar In + Secondary Rotational (Sro+SRi+Spi+SR)	

Table 2. The percentage share from total assumed work for each operation of machining divided into categories of parts

Machining operations	**Parts Category**				
	SPi	**SPi+SR**	**Sro+SPi**	**SRo+Spi+SR**	**Sro+SRi+Spi+SR**
Milling	100%	75%	30%	70%	55%
Turning			70%	15%	35%
Drilling		25%		15%	10%

Table 3. The number of parts in the series

The number of parts in the series			
Serial number	**Type of work**	**Quantity**	**%**
1	SPi	1	10
2	SPi+SR	1	10
3	SRo+SPi	2	20
4	SRo+SPi+SR	2	20
5	Sro+SRi+SPi+SR	4	40

If we analyze the flexibility of routing for five different parts from Table 1, the percentage unit flexibility of routing for a specific processing strategy can be determined through artificial intelligence software (OpenAI., 2021). Based on the following facts:

- The flexible cell DFMC1, which has components: CNC lathe, CNC milling machine, robot with slider,
- Processing five different parts; the first has a milling operation, the second has a drilling and milling operation that is performed on a milling machine, the third has a double turning

operation on DFMC1 or turning and milling on DFMC1, the fourth has milling and drilling on the milling machine DFMC1, and the fifth has turning, milling, and drilling on DFMC1, where milling and drilling are performed on the milling machine,

- Unit quantity of parts per group (first piece 1, second piece 1, third piece 1, fourth piece 1, and fifth piece 1), and
- asking the artificial intelligence the question: "What is the percentage flexibility of routing for milling operations on FMC1?" The answer received is:
- The percentage flexibility of routing for milling operations on FMC1 is given by the formula:
- Percentage flexibility of routing = (Number of possible routings / Total number of operations) * 100%
- Total number of operations: Total number of operations = Number of operations for the first part + Number of operations for the second part + Number of operations for the third part + Number of operations for the fourth part + Number of operations for the fifth part Total number of operations = 1 + 2 + 2 + 2 + 3 Total number of operations = 10
- For routing milling operations, there are three possible paths for operations on FMC1 (CNC milling machine). These operations can be performed on the first part, second part, and fourth part. Therefore, the number of possible routings is 3.
- Percentage flexibility of routing for milling operations on DFMC1 = (3/10) * 100% = 30% Therefore, the percentage flexibility of routing for milling operations on FMC1 is 30%.

Similar questions and answers obtained from the software are presented in Table 4.

Table 4. Percentage flexibility of routing for operations

Percentage flexibility of routing for operations	**TypeDFMC**	
	DFMC1[%]	**DFMC2[%]**
Percentage flexibility of routing for milling operations	30%	60%
Percentage flexibility of routing for drilling operations	20%	50%
Percentage flexibility of routing for turning operations	20%	67%

On the base of previously explained modeling knowledge with belief function of Dempster-Shafer theory, it is possible to create an appropriate evidence network (Figure 3). Flexibility for DFMC1 and the highest routing flexibility for DFMC2 are evident. For the group of parts consisting of 10% of parts from the first group, 10% of parts from the second group, 20% of parts from the third group, 20% of parts from the fourth group, and 40% of parts from the fifth group, it can be concluded that it has average routing flexibility values compared to the analyzed groups of parts DFMC1 and DFMC2 (DFMC1 = 0.0857 and DFMC2 = 0.8273).

Table 5 shows data indicating a change in beliefs about routing flexibility depending on the percentage content of individual groups of parts. It is evident that all groups of parts processed on DFMC2 have incomparably greater routing flexibility compared to DFMC1. Thus, the group of parts consisting of 30% of parts from the first group, 30% of parts from the second group, and 40% of parts from the fourth group has the highest routing flexibility for flexible cell DFMC1, and the lowest routing flexibility for DFMC2. For the group of parts consisting only of parts from the first and fifth classes (DFMC1 = 0.0752 and DFMC2 = 0.8637), the lowest routing.

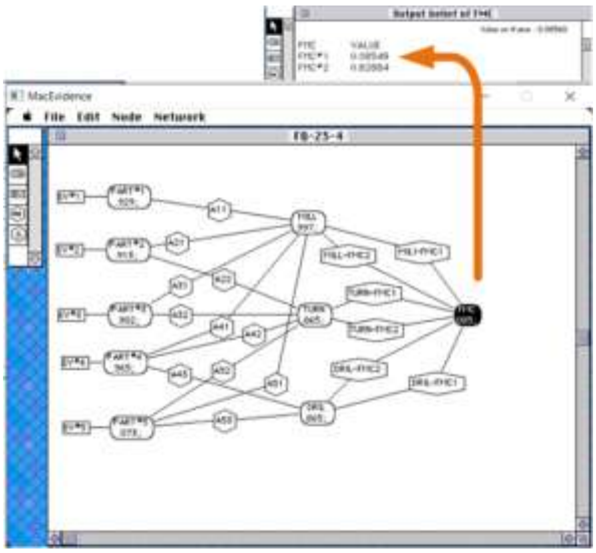


Figure 3. Evidence network with output belief

Table 5. Distribution of beliefs regarding routing flexibility

Number of group part.	Partial participation of the first, second, third, fourth and fifth categories in the group															Distribution of beliefs		
	I. SPi		II. SPi+SR			III. Sro+SPi			IV. SRo+Spi+SR				V.Sro+SRi+Spi+SR			$Bel(DFMC)$		
	Yes	No	Yes/No	Yes	No	Yes/No	Yes	No	Yes/No	Yes	No	Yes/No	Yes	No	Yes/No	*DFMC1*	*DFMC2*	*(DFMC1,DFMC2)*
1	0.1	0.9	0.0	0.1	0.9	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.4	0.6	0.0	0.0857	0.8273	0.087
2	0.1	0.9	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.3	0.7	0.0	0.0855	0.8283	0.086
3	0.2	0.8	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.0853	0.8299	0.084
4	0.2	0.8	0.0	0.3	0.7	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.1	0.9	0.0	0.0851	0.8309	0.084
5	0.3	0.7	0.0	0.3	0.7	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.0	0.0	0.0	0.0849	0.8319	0.083
6	0.3	0.7	0.0	0.4	0.6	0.0	0.2	0.8	0.0	0.1	0.9	0.0	0.0	0.0	0.0	0.0848	0.8322	0.083
7	0.4	0.6	0.0	0.1	0.9	0.0	0.1	0.9	0.0	0.1	0.9	0.0	3.0	0.0	0.0	0.0855	0.8288	0.085
8	0.3	0.7	0.0	0.3	0.7	0.0	0.0	0.0	0.0	0.4	0.6	0.0	0.0	0.0	0.0	0.0911	0.8130	0.096
9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0752	0.8637	0.061
10	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0790	0.8514	0.069
11	0.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0752	0.8537	0.069
12	0.0	1.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0832	0.8354	0.082
13	0.0	1.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0752	0.8637	0.061

4. CONCLUSION

FMC (Flexible Manufacturing Cell) is a manufacturing system that consists of flexible machines and equipment organized in a manufacturing cell. This system allows production to quickly adapt to changes in order to avoid production downtime. Didactic FMC (DFMC) system is typically a smaller and simpler manufacturing system used for educational purposes to provide students with practical experience in production. In this sense, the analysis of the routing flexibility of the didactic FMC is conducted in the technological system design phase, but the objectives of this analysis are different than those of real manufacturing systems.

In DFMC, the objective of routing flexibility analysis is to evaluate the system's efficiency in producing different products, as well as the system's ability to adapt to changes in the production program. This analysis is usually conducted to improve the performance of the didactic FMC and enable students to learn the basic concepts of production and production processes.

On the other hand, in real manufacturing systems, the objective of routing flexibility analysis is to improve production efficiency and increase the competitiveness of the company in the market. This analysis is usually conducted to improve the manufacturing system's ability to adapt to changes in the production program and market demand, as well as to minimize production costs.

In summary, although routing flexibility analysis is conducted in both types of FMCs, the objectives of the analysis and the way in which the results are applied are different.

In order to improve the quality of the teaching process, it is useful to find an adequate configuration of the group of parts intended for processing on the DFMC, which will adequately and clearly present a certain characteristic of the flexible system. In the presented example, one of the characteristics of FMCs, including DMFCs, is routing flexibility. Routing flexibility analysis as well as decision-making regarding routing flexibility can be successfully realized by applying the theory of belief functions - Dempster-Shafer theory and evidence nets developed on the basis of this theory.

In the exercise preparation phases, decisions are made about geometric, technological, kinematic, and flexible characteristics (routing flexibility) under conditions where there is no reliable knowledge about which parts, what configurations, and which technological processes will be used to process workpieces on CNC machines. In the formation of these decisions, artificial intelligence software and the theory of belief functions (Dempster-Shafer) play a crucial role. Proposed software solutions have successfully replaced expert knowledge used in the decision-making process, and the results obtained have justified the comprehensive benefits of this methodology.

References:

Aguirre, F., Sallak, M., Vanderhaegen, F., & Berdjag, D. (2013). An evidential network approach to support uncertain multiviewpoint abductive reasoning. *Information Sciences*, *253*, 110-125.

Browne, J., Dubois, D., Rathmill, K., Sethi, S., Stecke, K. (1984). Classification of Flexible Manufacturing Systems. *The FMS Magazine*, April 1984, 114-117.

Buzacott, J. A., & Mandelbaum, M. (1985). Flexibility and Productivity in Manufacturing Systems. Proceedings of the Annual IIE Conference, Los Angeles, CA, pp. 404-413.

Đapić, M., Lukuić, Lj., Pavlović, M. (2016). An Approach to Machine Tools Structure Selection for Wooden Product Machining Based on Evidence Networks. FME Transactions, 44(4), 365-373. doi:10.5937/fmet1604365D

Godinho Filho, M., Barco, C. F., & Tavares Neto, R. F. (2014). Using Genetic Algorithms to solve scheduling problems on flexible manufacturing systems (FMS): a literature survey, classification and analysis. *Flexible Services and Manufacturing Journal*, *26*, 408-431.

Goyal, A., & Bengio, Y. (2022). Inductive biases for deep learning of higher-level cognition. *Proceedings of the Royal Society A*, *478*(2266), 20210068.

Gupta, Y. P., & Goyal, S. (1989). Flexibility of manufacturing systems: concepts and measurements. *European journal of operational research*, *43*(2), 119-135.

Iqbal, M., Azam, M., Naeem, M., Khwaja, A. S., & Anpalagan, A. (2014). Optimization classification, algorithms and tools for renewable energy: A review. *Renewable and sustainable energy reviews*, *39*, 640-654.

Jiroušek, R., & Shenoy, P. P. (2014). Compositional models in valuation-based systems. *International Journal of Approximate Reasoning*, *55*(1), 277-293.

Lim, S. H. (1986). Flexibility in Flexible Manufacturing Systems - A Comparative Study of Three Systems. In: Managing Advanced Manufacturing Technology, C. A. Voss (Ed.), IFS (Publications) Ltd., Springer-Verlag, 125-147.

Mahdavi, I., Azar, A. F. M., & Bagherpour, M. (2009, December). Applying fuzzy rule based to flexible routing problem in a flexible manufacturing system. In *2009 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 2358-2364). IEEE.

Mascarenhas, M. B. (1981). Planning for flexibility. *Long Range Planning*, *14*(5), 78-82.

Mirkov, G. (2022). The Management Model of Didactic Flexible Cells using Technologies of Radio-Frequency Identification (Doctoral dissertation). Faculty of Engineering, University of Kragujevac, University of Kragujevac, Kragujevac.

Oaksford, M., & Chater, N. (2009). The uncertain reasoner: Bayes, logic, and rationality. *Behavioral and Brain Sciences*, *32*(1), 105-120.

Qiu, S., Sallak, M., Schön, W., & Ming, H. X. (2018). A valuation-based system approach for risk assessment of belief rule-based expert systems. *Information Sciences*, *466*, 323-336.

OpenAI. (2021). ChatGPT [Large language model]. https://chat.openai.com/chat

Shafer, G. (1976). A Mathematical Theory of Evidence. Princeton University Press.

Shenoy, P. P. (1992). Valuation-Based Systems: A Framework for Managing Uncertainty in Expert Systems. In L. A. Zadeh and J. Kacprzyk (Eds.), Fuzzy Logic for the Management of Uncertainty, pp. 83-104. John Wiley & Sons, New York.

Yilmaz, O. S., Davis, R. P. (1987). Flexible Manufacturing Systems: *Characteristics and Assessments. Engineering Management International*, 4(3), 209-212.

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