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Selection of the Cobot Workstation for the Learning Factory by using the Multi-Criteria Analysis

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Abstract

The collaborative robots (cobots) are one of the drivers of Industry 4.0, because they allow the automation and semi-automation of the process, yet allowing the flexibility of the production plan. The main area of cobots' application are the assembly processes. For safety reasons, the assembly process is the most common process in the Learning Factory concept. Therefore, integration of cobot workstation in the Learning Factory assembly process is crucial to demonstrate modern aspects of the assembly, and manufacturing, as well. However, it is not an easy task, since proper design for cobot workstation must be selected to allow flexibility and reconfiguration of the Learning Factory. In this research, a multi-criteria analysis approach is used to select optimal design of the cobot workstation for application in the Learning Factory. The aim was to select the mobile and flexible workstation for cobot Franka Emika that will satisfy educational and research needs of the Lean Learning Factory at University of Split. Two different multi-criteria analysis methods were used for evaluation and ranking of alternatives: SAW (Simple Additive Weighting) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution). The comparison of the methods is presented and selection of the optimal design of the cobot workstation has been made. In the near future, selected workstation will be manufactured, assembled and used in the Learning Factory's everyday activities.

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1. Introduction

It is hard to imagine automation without robots. However, some operations are quite challenging for automation, especially assembly operations. It is very hard to replace a human worker in assembly, since his/her ingenuity and problem-solving ability can easily find the best way to assemble parts. The robots do not possess these abilities. Furthermore, their movements and fingertips are not flexible and adaptable as human movements and motor-skills, so they have problem assembling parts with complex geometry or similar. The solution of these issues is collaborative robot (cobot) which is not replacing human worker, instead it collaborates with human in the assembly [1]. It is the reason why the cobots are driver of automation in assembly processes of Industry 4.0 [2].

Since the Learning Factories, especially at Universities, are mostly focused on assembly processes, an integration of cobot in the assembly process is a logical direction of the Learning Factory development [3]. First of all, a proper cobot must be selected [4] and purchased. The second step is the design of the cobot workstation for an easy implementation in the Learning Factory. This second step represents the topic of this research.

Namely, collaborative robot Franka Emika Panda has been purchased and installed in Lean Learning Factory at FESB, University of Split, Croatia (Fig. 1). The robot was installed on a kind of a testbed with a plan to design a special workstation for it.

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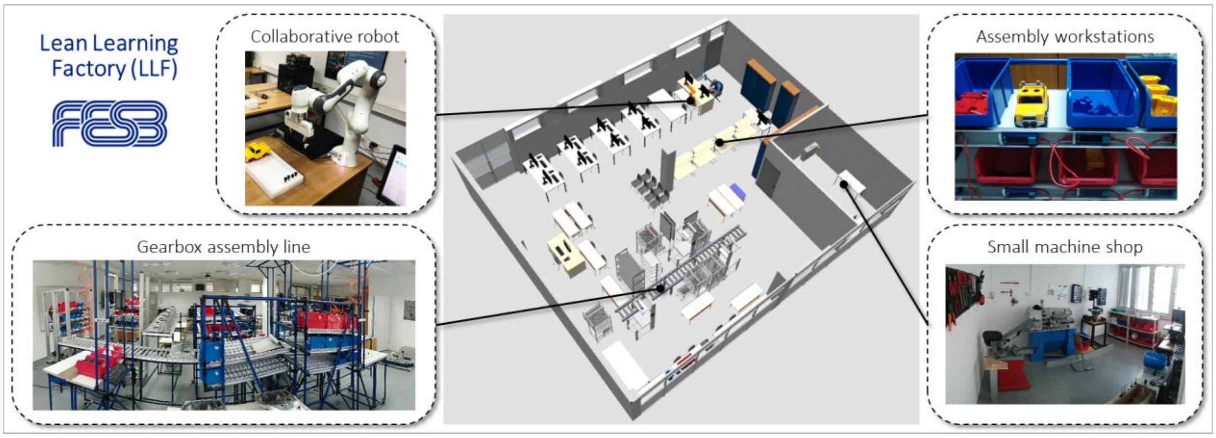

Fig. 1. Layout of Lean Learning Factory at FESB, University of Split.

There are many possible designs for the robot station, but, in this case, the workstation should have some kind of adaptability to existing assembly lines in the Learning Factories. It should also be plug & play, which means that no calibration is required. And, at the end, it shouldn't be expensive and complex to assemble. So, it seems to be a multi-criteria problem which needs to be solved with a proper method [4].

There are many Multi-Criteria Analysis (MCA) and Multi-Criteria Decision-Making (MCDM) methods which can solve a problem of evaluation and ranking on alternatives based on multiple criteria. According to scientific database Scopus and Current Contents, the most popular method is Analytic Hierarchy Process (AHP) [5] followed by the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method [6]. The next two methods are well-known outranking methods PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) [7] and ELECTRE (ELimination and Choice Expressing REality) [8]. And there are dozens of other MCA/MCDM methods (FlowSort, MOORA, MACBETH, VIKOR, REGIME, QUALIFLEX, PAPRIKA, etc.), but it is appropriate here to mention the utility-function-based method MAUT (Multi-Attribute Utility Theory) [9] and the most simple method SAW (Simple Additive Weighting) [10]. The popularity of these six methods in scientific papers is presented in Fig. 2.

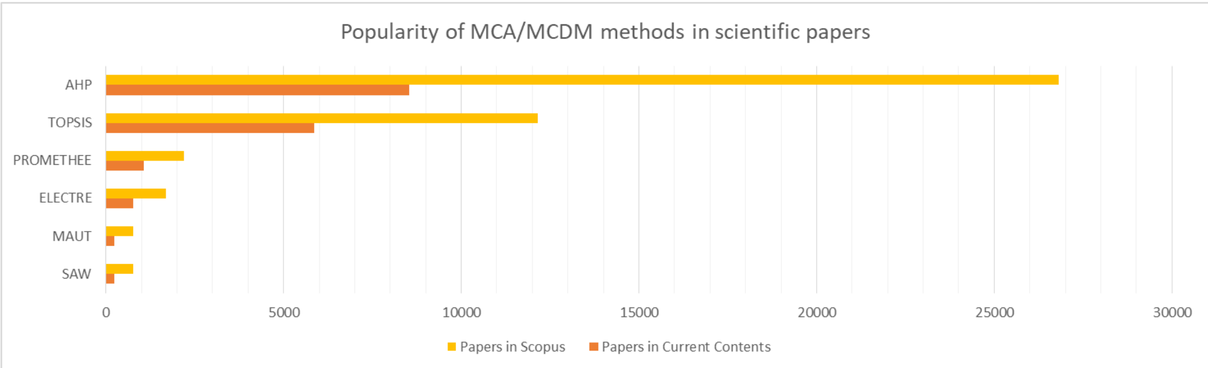

Fig. 2. MCA/MCDM methods popularity according to scientific database Scopus and Current Contents.

When it comes to books, all type of books (monographs, textbooks, etc), the popularity-based ranking of these six methods is similar. Nevertheless, it was identical in 2016 according to Google Books Ngram statistics (Fig. 3). However, the ranking slightly changed in last 5 years, since the TOPSIS method has overtaken AHP method. Furthermore, TOPSIS and PROMETHEE method have most significant increase in popularity in last 10 years.

Therefore, two methods will be used in this research for selection of the optimal robot station: TOPSIS method which is one of the most popular methods, and SAW method which is one of the simplest and the least popular methods. A multi-criteria problem of selection of the optimal robot station will be submitted to these two methods, the results will be compared and some conclusions will be drawn.

These two methods have been used, since they have an advantage that user doesn't need to define any parameters except his/her decision-making preferences. The criteria weights represent decision-maker's preferences, but in this research equal criteria weights are used. At the end, a discussion can be made if the approach of these methods with no need to define any parameter is justifiable, or not.

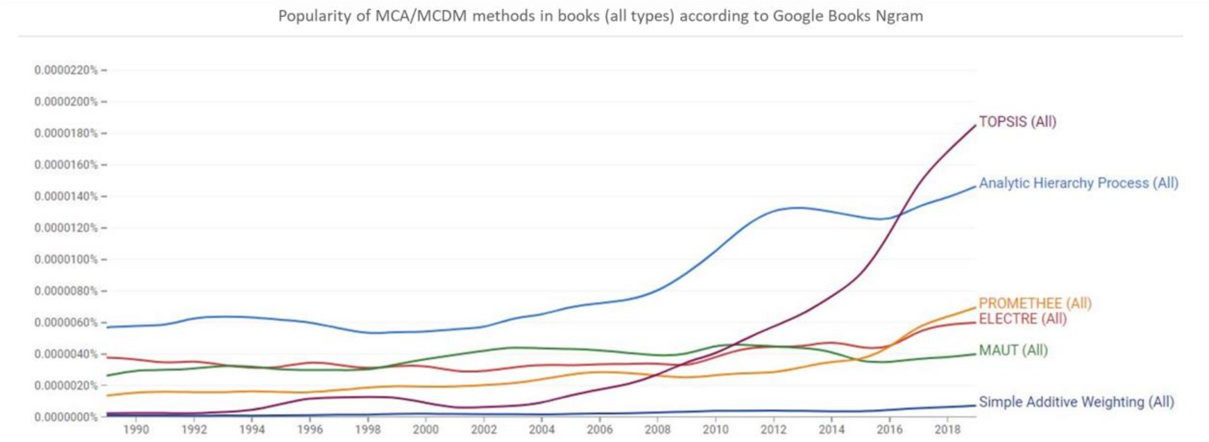

Fig. 3. MCA/MCDM methods popularity according to Google Books Ngram statistics.

2. Methodology

The benchmarking of the robot stations market has pointed out to three basic designs: the robot station is attached to a workbench (Fig. 4a), the robot station is adjustable but without a workbench (Fig. 4b), and the robot station is a workbench with robot installed onto it (Fig. 4c), or the. These three variants represent three alternatives for multi-criteria analysis.

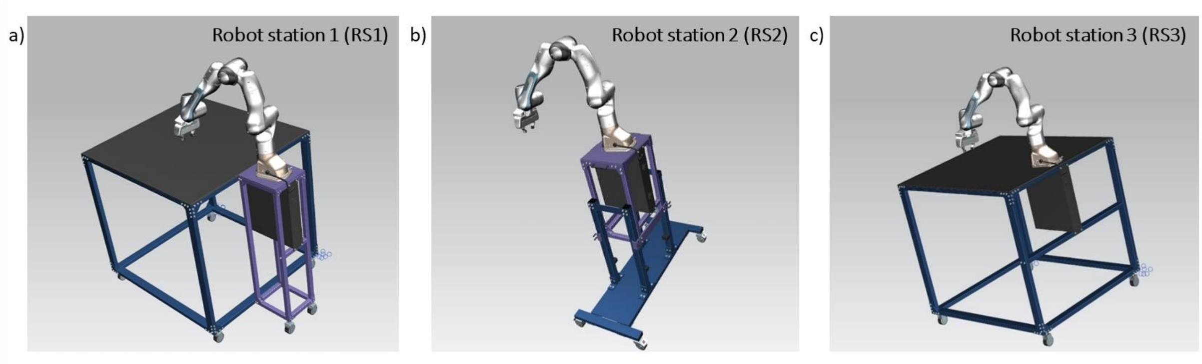

Fig. 4. Three variants of robot station design: a) Robot station 1 (RS1); b) Robot station 2 (RS2); Robot station 3 (RS3).

Since the idea is to purchase parts and materials and to assemble the selected robot station in Learning Factory, there are two criteria that should be minimized: material cost and assembly complexity. The next important criterion is modularity. For instance, RS3 is a robot installed onto a workbench, so its modularity is low; RS1 is attached to a workbench which means a couple of different workbench could be used or the robot could be attached to assembly line, so the modularity is moderate; and RS2 doesn't have a workbench so it is completely modular. And, at the end, the last criterion shows if the calibration of the robot is needed, and it is not needed for RS1 and RS3 since they have their own workbench for which they are calibrated, but it is needed for RS2 which doesn't have a workbench and needs to be calibrated each time a working environment changes. These four criteria and their information are presented in Table 1, and Table 2 represents criteria evaluations of the alternatives.

Table 1. Criteria information.

	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Name	Material cost	Assembly complexity	Modularity	Calibration-not-required
Description	Total cost of all material and parts needed to assemble the station.	Qualitative approximation of how much the station is complex to assemble.	Qualitative approximation of how the station can be used as a module.	Binary criterion – it is true (1) if the calibration of the station isn‘t required.

Unit	Cost value in Croatian currency (HRK)	Scale: 1 - low 2 - moderate 3 - high	Scale: 1 - low 2 - moderate 3 - high	Binary: 0 - no 1 - yes
Goal	Minimize	Minimize	Maximize	Maximize
Weight	25%	25%	25%	25%

Table 2. Criteria evaluations of alternatives.

Alternatives	Criterion 1 Material cost (HRK)	Criterion 2 Assembly complexity (scale: 1 - low, 3 - high)	Criterion 3 Modularity (scale: 1 - low, 3 - high)	Criterion 4 Calibration-not-required (binary: 0 - no, 1 - yes)
Robot station 1 (RS1)	3820.9	2	2	1
Robot station 2 (RS2)	2501.5	2	3	0
Robot station 3 (RS3)	2891.9	1	1	1

The data from Table 1 and Table 2 will be used as an input data for the SAW and the TOPSIS method.

3. Results

3.1. Selection of the robot station by using the SAW method

The SAW method consists of two main steps: normalization of the criteria evaluations based on the highest criterion value, and calculating scores of alternatives based on criteria weights. The normalized criteria evaluations are presented in Table 3.

Table 3. Criteria evaluations of the alternatives normalized by the principle of the SAW method.

Alternatives	Criterion 1 Material cost	Criterion 2 Assembly complexity	Criterion 3 Modularity	Criterion 4 Calibration-not-required
Robot station 1 (RS1)	0.655	0.500	0.667	1.000
Robot station 2 (RS2)	1.000	0.500	1.000	0.000
Robot station 3 (RS3)	0.865	1.000	0.333	1.000

Score V_i of alternative is calculated by mutual addition of criteria evaluations multiplied with criterion weight. The alternatives with higher score gets a higher rank. In this case, the best ranked alternative is RS3, the second ranked is RS1, and the last ranked alternative is RS2 (Table 4).

Table 4. Results of the SAW method: scores and ranks of alternatives.

Alternatives	Score V_i	Rank
Robot station 1 (RS1)	0.705	2
Robot station 2 (RS2)	0.625	3
Robot station 3 (RS3)	0.800	1

According to SAW method, a cobot workstation should be designed like RS3. The second option is RS1, and the last option is RS2. It means that two designs with workbench have outranked the design without the workbench, although its modularity is the best one and it is the cheapest one.

3.2. Selection of the robot station by using the TOPSIS method

The TOPSIS method consists of four main steps: normalization of the criteria evaluations based on vector normalization, pondering of normalized criteria evaluations by criteria weights, construction of ideal and anti-ideal alternative, and calculating scores of alternatives based on the Euclidean distance from ideal and anti-ideal alternative. The normalized criteria evaluations have been pondered by criteria weights and presented in Table 5.

Table 5. Criteria evaluations of the alternatives normalized and pondered by criteria weights.

Alternatives	Criterion 1 Material cost	Criterion 2 Assembly complexity	Criterion 3 Modularity	Criterion 4 Calibration-not-required
Robot station 1 (RS1)	0.177	0.167	0.134	0.177
Robot station 2 (RS2)	0.116	0.167	0.200	0.000
Robot station 3 (RS3)	0.134	0.083	0.067	0.177

The ideal alternative is constructed by combining the best criteria evaluations on each criterion. The anti-ideal alternative is constructed by combining the worst criteria evaluations on each criterion (Table 6).

Table 6. Ideal and anti-ideal alternative and their criteria evaluations.

Alternatives	Criterion 1 Material cost	Criterion 2 Assembly complexity	Criterion 3 Modularity	Criterion 4 Calibration-not-required
Ideal V^+	0.116	0.083	0.200	0.177
Anti-ideal V^-	0.177	0.167	0.067	0

Score Q_i of alternative is calculated based on the Euclidean distance S_i^+ from ideal alternative and the Euclidean distance S_i^- from anti-ideal alternative (Table 7). The alternative which has the shortest distance to ideal and the greatest distance to anti-ideal is the best one.

Table 7. Results of the TOPSIS method: distances from ideal and anti-ideal alternatives, score and rank.

Alternatives	Distance S_i^+	Distance S_i^-	Score Q_i	Rank
Robot station 1 (RS1)	0.123	0.189	0.606	1
Robot station 2 (RS2)	0.195	0.147	0.429	3
Robot station 3 (RS3)	0.135	0.200	0.597	2

According to TOPSIS method, a cobot workstation should be designed like RS1. The second option is RS3, and the last option is RS2. Similar to the results of the SAW method, two designs with workbench have outranked the design without the workbench.

However, there is an important difference in results between the SAW and TOPSIS method: the first ranked alternative. SAW method resulted with RS3 as the best ranked, and TOPSIS method resulted with RS1 as the best ranked. Comparison of the results is given in Fig. 5. The TOPSIS score of RS1 and RS3 is almost the same, with RS1 having a slightly higher score and the first rank. In the SAW method there is no such a doubt, RS3 completely outranked RS1. The question remains: which ranking is more logical?

The TOPSIS method is one of the most popular MCA/MCDM methods, and SAW method is the simplest and perhaps too simple MCA/MCDM method. So, it is obvious that the TOPSIS ranking should be better, and RS1 should be selected as the best alternative.

However, TOPSIS method is wrong in this case, and the SAW ranking is more logical. Since the criteria weights are the same, it is clear from Table 2 that RS3 has the best values of two criteria, second best value of one and the worst value of another criterion. RS1 has the best value of one criterion, second best value of another criterion, and the worst value of two criteria. So, it is obvious that RS3 should outrank RS1, but it didn't happen in the TOPSIS method, as it happened in the SAW method.

Furthermore, since RS2 compared to RS1 has the better value of two criteria, same value of one criterion and worse value of last criterion, it is clear that RS2 should outrank RS1. So, the final ranking of alternatives should be RS3 as 1st, RS2 as 2nd and RS1 as 3rd, as long as logical criteria evaluations scale is used. But, none of these two methods didn't result with this ranking!

The problem lies in a fact that both of the methods, SAW and TOPSIS, have too simple process of normalization of criteria evaluations. They are simpler to use because of that, since user doesn't need to define any parameter, but they are not reliable. Therefore, a bit complex method, like PROMETHEE or ELECTRE, with proper definition of parameters, i.e. decision-maker's perception of scale for each criterion, will give much better results. On the other hand, the AHP method doesn't rely on definition of parameters that represent decision-maker's perception of scale for each criterion, but this is actually done during the process of pair-wise comparison of alternatives. However, for a while, there is a debate among scientist about reliability of the AHP method [11, 12], which is one of the most popular MCA/MCDM methods, so many scientist rather prefer to use PROMETHEE and ELECTRE method. From this research, it is obvious that also very popular TOPSIS method could have similar reliability issues as AHP method has. Therefore, the conclusion and recommendation of this research is to choose more complex, but also more reliable methods as PROMETHEE or ELECTRE for solving multi-criteria problems.

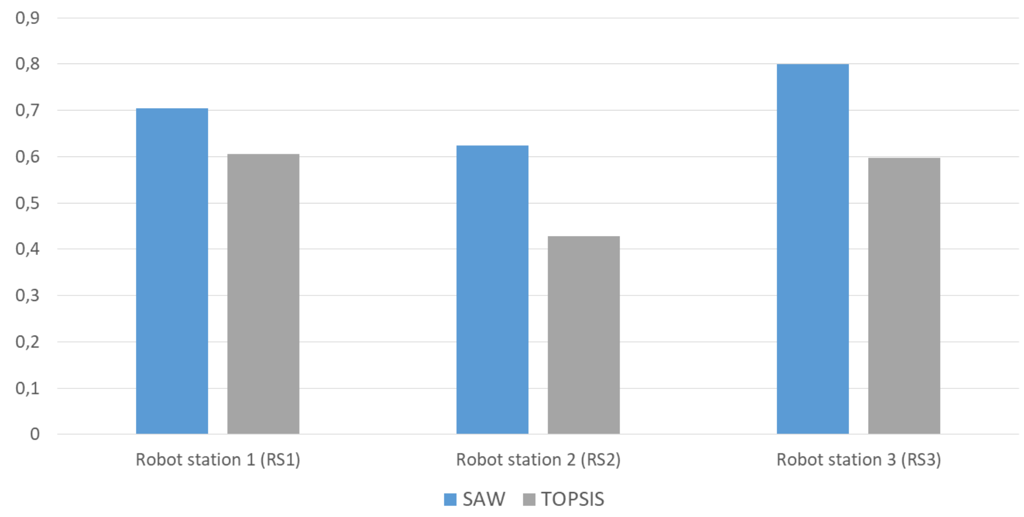

Fig. 5. SAW and TOPSIS results mutually compared.

4. Conclusion

In this paper, a problem of design selection of robot station, which will be used as cobot workstation in the Learning Factory, is presented. Two MCA/MCDM methods are used – SAW method and TOPSIS method – and their results are mutually compared. Surprisingly, the ranking provided by the SAW method seems to be more logical than the ranking provided by the TOPSIS method. However, two best ranked alternatives in TOPSIS method have almost the similar score. That is why the alternative RS3 with SAW rank 1st and TOPSIS rank 2nd will be selected as the design for the cobot workstation, which will be built in the near future. The future research will be based on usage of PROMETHEE and/or ELECTRE method to see how they perform on this and similar problems.

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