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MANUFACTURING
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Suitability analysis of using industrial robots in manufacturing

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Abstract. Manufacturing industry robotization is spreading into wider range of processes. Determination if robotization is suitable for the company is one of the most critical issues before selecting industrial robot and designing the robot cell. A survey was carried out among Estonian small and medium sized manufacturing enterprises (SMEs) for this study to determine the utilization of industrial robot (IR) in the industry. More specific study of production unit was conducted, using gathered information, to estimate how the objectives of the production cell design were achieved. The aim of the present scientific work is to map the knowledge whether robotization is suitable or not for the company or working processes and to appoint parameters obtained after using the robot cell for practical manufacturing processes. The study results comprise the suitability assessment method with the set of criteria and key performance indicators (KPIs), that best describe implemented production unit profitability and help SMEs to gain additional economic-technical information for future robot-based unit development.

Key words: industrial robots, feasibility analysis, suitability analysis.

1. INTRODUCTION

Suitability analysis is the process and procedure used to establish a system that meets the needs of users. Suitability of robotization is a basic question for managers who are planning changes in the company. For producing goods, companies have to perform different processes and industrial tasks. There are certain aspects why industrial robots are used for those processes. Theoretically, the basic aspects concern humans, productivity and quality [1–3].

The widest areas using industrial robots are: welding, machine tool servicing, assembling, painting, loading-unloading, packaging, palletizing, and medical applications. Welding ranks among the most important joining processes and has special features for the industrial robots, such as programming task sequences, free definition and parameterization of robot positions/orientations, high repeatability and positioning accuracy of moving paths, high speed of end effector, minimum six degrees of freedom (6DOF), variable payloads depending on the welded products (2–150 kg), advanced programmable logic controllers (PLCs). The vision, strategy and action plans for implementation of robots are described in [4] and statistics about using robots in industry can be found in [5].

Literature review and efficiency analysis of IR cells are important basis for gathering information. To estimate the suitability of using industrial robots in different application areas, it is necessary to analyse the applications of the robot in the industry and to solve a decision-making task.

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2. BACKGROUND

Suitability analysis belongs to the tasks of dual approach. From one hand, it is an application area for the efficient use of industrial robots and on the other hand it supports decision making methods. The decision maker (expert) must have an excellent understanding about the application area and should be familiar with the factors influencing the effective use of industrial robots. For this purpose, a robot-based manufacturing cell performance evaluation conceptual model was developed, which is based on a recursive decision-making procedure [6]. In the model shown in Fig. 1, there are four groups of parameters: product features, robot cell features, elements of evaluation and general output description. The first two groups are the parameters of the design level (parameters of the product portfolio and their manufacturing processes) and the last two groups are the execution outcomes (different KPIs, that measure, and critical success factors – cost factors, level of achieving the general objectives, dynamics of effectiveness, employee competencies, etc.). These interactions reflect the suitability of using the real IR cell in the company.

The main concern in the suitability analysis process is to find the best solution, according to the set of criteria using the method, which allows the most realistic input (importance) of each criterion. There are different possibilities to influence the roles of criteria: the equal weight (EQW) heuristic [7], the weighted additive (WADD) rule [7]. However, the main risk is over-estimating some of the criteria or not paying enough attention to others. Therefore, artificial intelligence (AI) methods may be used [8].

Analysing industrial robot's applications for welding, there were developed three general groups of parameters, shown in Table 1. Those listed parameters have the greatest influence to the suitability of using welding robots in the company.

Having knowledge about the welding process and parameters make the welding process more efficient. It is possible to find the tools for suitability analysis. To solve the engineering task, such as making a decision about the suitability of welding robots in the company, multiple criteria should be used (see Table 1). Each decision corresponds to a variable, relation or predicate, whose possible values are listed among the condition alternatives. Each action is a procedure or operation

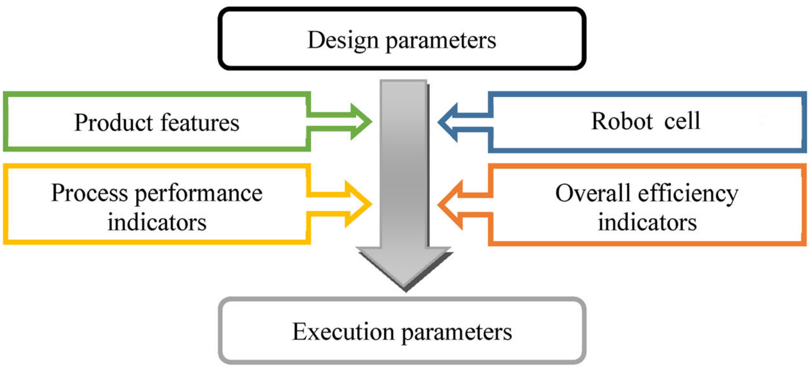

Fig. 1. Efficiency analysis of implementing robot cells in the companies.

Table 1. Suitability criteria for robot welding

Product view	Technology view	Objectives' view
1. The products are complicated from the technological point of view 2. The products can be classified into product families 3. The products are produced in repeatable batches 4. The products are of high quality 5. It is necessary to use welding fixtures	1. Experiences in MIG/MAG and TIG welding 2. Competences in welding technologies 3. Welding processes have great importance in the company's production processes 4. There are already experiences with robot welding 5. It is necessary to increase the productivity of welding processes	1. To shorten the throughput time 2. To increase the productivity in the workplace 3. To increase the product quality 4. To increase the precision of delivery 5. To reduce the product cost

to perform, and the entries specify whether or in what order the actions should be performed for the set of condition alternatives the entry corresponds to.

3. ANALYTIC HIERARCHY PROCESS

Solving the engineering decision making problem of IR cell suitability, which has multiple criteria and alternatives, is a difficult task. One of the techniques for solving multi-criteria decision making (MCDM) problems is analytic hierarchy process (AHP). AHP was proposed by Saaty [9] and developed further by [10,11]. Those methods use fundamental scale of relative importance to construct a pairwise comparison matrix of attributes. Likewise, consistent weight of attributes is determined, which help evaluating composite performance score of alternatives. The alternatives are then ranked according to their composite performance score. Several steps and principles should be considered and understood for constructing a MCDM problem solving tool. The steps are the following:

(1) Developing the hierarchy criteria model for decision;
(2) Deriving priorities by pair-wise comparison for the criteria. Pair-wise comparison scales are shown in Table 2;
(3) Determining local priorities for alternatives;
(4) Calculating and adjusting the consistency:
   (a) Multiplying the matrix of judgements by the eigenvector, obtaining a new vector ($A\omega$);
   (b) Dividing each component of a new vector of $A\omega$ by the corresponding eigenvector element;
   (c) The mean value from the point b is the estimated for λ_{max};
   (d) Calculating the consistency index (CI) by:

$$CI = (\lambda_{\max} - n)/n; \tag{1}$$

   (e) Calculating the consistency ratio (CR) by:

$$CR = CI/RI; \tag{2}$$

   (f) Checking the consistency of the hierarchy. CR should be below or equal to 10 %;
(5) Populating the judgement matrix with input data: quantitative data, such as product payback period total investment etc. are normalized by using Eq. (3). Dimensions, mass etc., are normalized by using Eq. (4). Qualitative data, such as complexity of operations, manufactured parts precision, experience and competencies of engineering stuff and workers, etc., are graded by the scale of 1–5 and normalized.

$$Z = 1 - \frac{x - x_{\min}}{x_{\max} - x_{\min}}, \tag{3}$$

$$Z = \frac{x - x_{\min}}{x_{\max} - x_{\min}}; \tag{4}$$

(6) Making the final decision.

4. CASE STUDY

Production cells were investigated in twenty SMEs with the number of employees ranging from 20 to 150. They produced different parts for agricultural and forestry machines, small tractors, high speed trains, lifts' components, wind generator rotors and other sheet metal products. The information was acquired by interviewing companies' management, engineering staff and data extracted from the enterprise resource planning (ERP) software. Data gained from the interviews and ERP system contained both, quantitative and qualitative data. From the collected data, the information about the robot welding production units was the only one used for the following suitability analysis.

Three performances of production units were stated as a benchmark for the suitability analysis. Production cells, shown in Table 3, were chosen by their excellent KPIs' outcomes. KPIs were selected according to the performance evaluation model [6] and they are as follows: discounted payback period (DPP), cell utilization (CU) and overall equipment effectiveness (OEE).

Table 2. Pair-wise comparison scale assessment

Importance	Description
1	Equal Importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Values between two adjacent values should be in considerations
Inverse	If activity (i) got a point compared with activity (j), then (j) has the opposite value compared to (i)

Table 3. Production unit's description and performances

Company	Production cell	Products	Shifts	DPP, years	CU, %	OEE, %
No. 1	Yaskawa IR, two axes positioner	Heat exchangers	2	3	51	72
No. 2	ABB IR, single axes positioner	Trailer frames	2	2	40	70
No. 3	Yaskawa IR, single axes 2-station positioner	Forestry machine frames	1 (2)	3	45	70

5. CRITERIA AND SUB-CRITERIA

Regarding this study, the main task of multi criteria decision analysis (MADM) is to estimate the suitability index and it is based on the following criteria and sub-criteria (see Fig. 2):

- Production unit (PU):
  - cost (C): total investment (C1), cost of utilities (C2), running costs (C3);
  - maintenance (M): maintenance cost (M1), emergency maintenance cost (M2);
  - level (L): use of CAD/CAM (L1), automated storage (L2), machine vision (L3).
- Product (P):
  - physical properties (PP): complexity of parts (T1), parts manufacturing precision (T4), mass (T6);
  - productivity (PR): product families (T2), patch size (T3), patch repeatability (T9), overall welding ratio (TE3), average cycle time (TE9), average setup time (PR2), quality assurance (E2).
- Company environment (CE):
  - workforce (WF): workstation fulfillment (E1), workers salary (E6), production engineer's involvement (E8), shifts (W2), durations of shifts (W3);
  - performance indicators (PI): increment of productivity (E4), increment of on time delivery OTD (E9), increment overall equipment effectiveness OEE (E10), payback period (K1);
  - experiences (E): experiences with MIG/MAG, TIG (TE1), competencies in welding technology (TE2), experiences with robotization (TE4), experiences with jigs and fixtures (TE7), workstation organization level (TE8), overall automatization level (TE10).

6. PERFORMANCE SCORES

The assessments obtained from the decision makers are made by pairwise comparisons. Performance scores and consistency ratio are calculated and given in Tables 4 and 5.

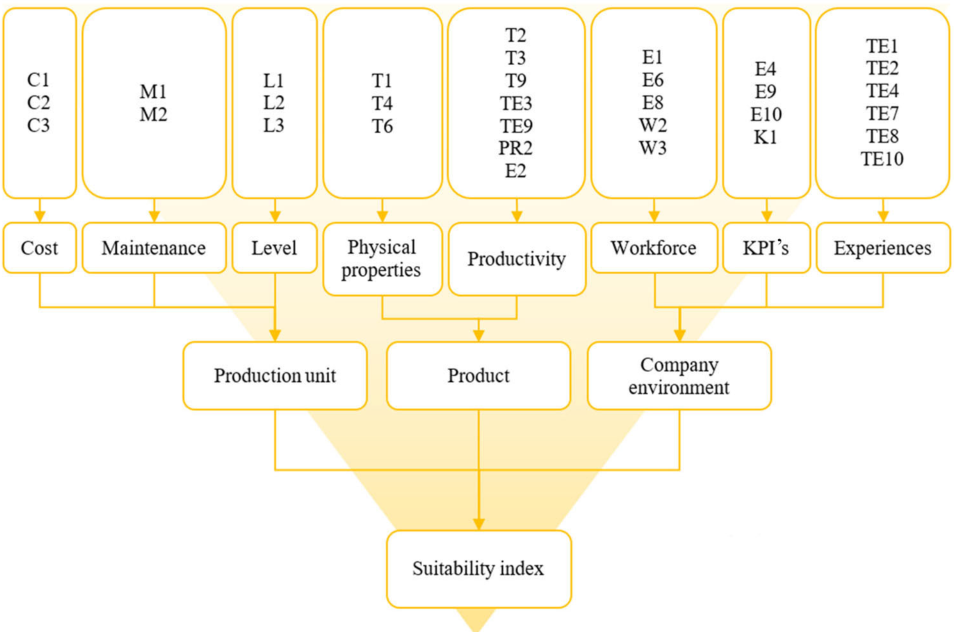

Fig. 2. Production cell suitability hierarchy.

Table 4. Performance scores of main criteria

Criteria	CR	Priority	Criteria	CR	Priority
Production unit	1.9	21	Physical properties	0	66.7
Product		24	Productivity		33.3
Company environment		55	Workforce	9.8	19.5
Cost	5.6	51.3	Performance		8.8
Maintenance		8.1	Experiences		71.7
Level		40.6			

Table 5. Sub-criteria, local performance scores

Criteria	CR	Priority	Criteria	CR	Priority	Criteria	CR	Priority
C1	7.4	74.3	T2	8.9	4.4	W3	2.6	18
C2		6.3	T3		18.1	E4	7.6	23.8
C3		19.4	T9		35.5	E9		28
M1	0	66.7	TE3		9.6	E10		8.9
M2		33.3	TE9		16.6	K1		39.3
L1	5.6	26	PR2		7.5	TE1	7.7	20.2
L2		41.3	E2		8.3	TE2		24.5
L3		32.7	E1	2.6	25.4	TE4		20.6
T1	5.6	41.3	E6		33.9	TE7		8.8
T4		32.7	E8		7.5	TE8		10.1
T6		26	W2		15.2	TE10		15.8

Explanations for the abbreviations are given in paragraph 5. Criteria and sub-criteria.

7. DECISION MATRIX

The normalized inputs are multiplied by their corresponding performance scores and the local and global scores are summed up. Results are shown in Table 6.

8. DISCUSSION AND CONCLUSIONS

In this study an AHP based suitability analysis for robot integrated production cells was developed. Twenty production cells in different industries and at different levels were investigated. Based on the literature, review input parameters were selected, criteria set up and hierarchy of the problem were developed. To ensure the objectivity of experts' pairwise comparisons of the responses of criteria, consistency ratio was calculated and controlled. For testing the developed tool, a case study approach was used. Three welding cells were selected based on their excellent KPIs' outcomes and set as a benchmark for suitability analysis. The highest overall suitability score was obtained in case of No. 3 with index of 0.17. The extremely high score was received in both, product and company environment categories, i.e. 0.849 and 0.810, respectively. The suitability analyses confirmed an excellent choice of product to be produced in a well-organized cell and automated company environment. For decision of suitability, four categories were proposed in Table 7, based on suitability criteria for robot welding, shown in Table 1.

For more precise results, it is possible to simulate the planned robot cell and to calculate the break-even point. Having enough competence in all these areas is quite sophisticated. Therefore, the tool which gives the possibilities to estimate the suitability of using industrial robots for the automation of a certain manufacturing

Table 6. Suitability index results

Production cell	Production unit	Product	Company environment	Suitability index
Company cell No. 1	0.567	0.699	0.664	0.652
Company cell No. 2	0.494	0.709	0.804	0.716
Company cell No. 3	0.524	0.849	0.810	0.717

Table 7. Suitability decision categories

Suitability index	Decision	Description
Smaller than 0.25	No expediency	Products portfolio, analysis of the current process and general conditions are indicating the lack of essential need for using robots in the company.
Smaller than 0.5	To a certain extent expedient	There is indicated the strong point (products, process, general conditions) and also the problematic places. The final decision lays on the industrial expert.
Smaller than 0.75	Robotization is recommended	There are indicated some risks which are not so much important.
Higher than 0.75	Robotizing is feasible	Each group (product, process, manufacturing conditions) has an index higher than 0.75, which gives a solid knowledge that robotization of the process would give significant benefits to the company.

process, is important in the early stage of planning. For future work, more robot integrated processes like machine tending, palletizing, etc. can be added to the tool.

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Tööstusrobotite kasutatavuse sobivusanalüüs

Tavo Kangru, Jüri Riives, Kashif Mahmood ja Tauno Otto

Tootmisettevõttes on määrava tähtsusega enne robottootmisüksuse loomist läbi viia tööstusrobotite sobivusanalüüs. Selle väljatöötamiseks tehti Eesti väikese ja keskmise suurusega ettevõtete hulgas uuring, määramaks tööstusrobotite kasutust. Kogutud andmete põhjal viidi läbi spetsiifilisem tootmisüksuste uuring, millega hinnati tootmisrakkude projekteerimisel püstitatud eesmärkide saavutamist. Tulemusena loodi tööstusrobotite sobivuse hindamise meetod koos kriteeriumide ja tulemuslikkuse võtmenäitajate kogumiga. Hindamismeetod võimaldab hinnata rakendatud tootmisüksuse kasumlikkust ja saada täiendavat majanduslik-tehnilist teavet tulevaste robottootmisüksuste arendamiseks.