International Journal of Manufacturing Economics and Management
ISSN 2784-1278 ISSN-L 2784-1278, Vol. II, No. 1 / 2022
https://doi.org/10.54684/ijmem.2022.2.1.6

SOME ASPECTS REGARDING THE SELECTION OF INDUSTRIAL ROBOTS IN MANUFACTURING OR ASSEMBLY PROCESSES

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Abstract: The current period involves a short product life, associated with frequent changes in the product range. In order to cope with the new world economic conditions, a high degree of automation of production and assembly processes is required. As a result, industrial robots must also meet a new level of flexibility and versatility. It is now clear that it is very important to evaluate the performance as well as the safety characteristics, but especially the compatibility with the existing production system, as well as the compatibility with the possible evolution of the production system or even the substantial modification of the tasks of the industrial robot in a new production system, totally modified from the previous one. This requires the formulation of evaluation methods with relevant design metrics and quantitative methods based on simulations, which can support the mechanical designer of the robot, but especially the production system manager, to correlate the load-based performance characteristics, compatibility and safety of the industrial robot, taking into account the wide variety of possible solutions.
Key words: industrial robot, AHP method, industrial engineering, multi-criteria decision-making, sensitivity analysis.

1. INTRODUCTION

Today's industry uses industrial robots (IR) intensively. They are used in a wide range of applications in the semiconductor industry, in the automotive industry, in the plastics and metals processing industry, but also in other complementary industries. Where repetitive operations occur, robots are very easy to apply, especially in difficult places of work or in places dangerous to human operators.

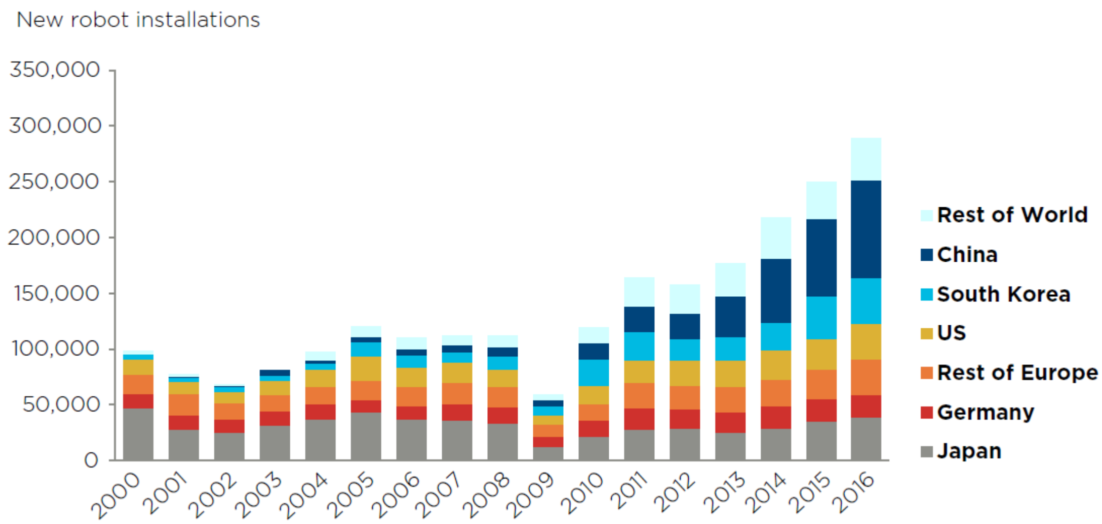

Fig. 1. Robot installations between the years 2000-2016, [10]

Initially, robots were used for mass or mass production, but as technology advanced and the cost of implementing robots decreased, new opportunities arose to be integrated into relatively small or medium-scale production areas.

Industrial robot as defined by ISO 8373/2012 is “an automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications”. There are many studies in the literature that try to determine the optimal selection of an industrial robot, for its integration into a production system [1, 2, 3, 9, 11, 13, 14].
There are pros and cons to the use of industrial robots in production, often political or economic views because in today's world industry has to deal with globalization, market competition, greening and especially sustainability. Rarely does technological opinion take precedence in decision-making, although this is particularly important, perhaps the most important factor. The application of industrial robots is particularly necessary and in this decade an even more substantial increase is estimated. The benefits of using industrial robots are:

- *High production quality*. Along with the emergence of industry standards 40, 3D rapid prototyping printers, industrial robots find their place in raising production quality and through the safety of manufacturing processes. In addition to these, other benefits are: reduced manufacturing cycle time, real-time monitoring and improved preventive maintenance in production.
- *Maximum productivity*. An industrial robot increases the speed of manufacturing processes, mainly robots work 24 hours and 7 days a week. Robots do not need breaks or changes in working hours.
- *Increasing safety in production*. The use of robots for repetitive tasks means reducing the risk of accidents for operators, especially when manufacturing takes place in difficult production conditions. In addition, supervisors can monitor the production process from a remote location.
- *Reduction of production costs*. Labor costs are reduced much faster when robots are used. This involves releasing human operators from repetitive work and using them especially in areas where robot programming and maintenance is needed.
- *Retention of jobs in the domestic industry*. There are opinions that the introduction of robots involves the dismissal of employees, but this is not absolutely necessary. Industrial robots must be integrated into a series of production operations that require human expertise. Most often, not all operations can be performed by industrial robots, especially when decisions are needed that only humans can make.

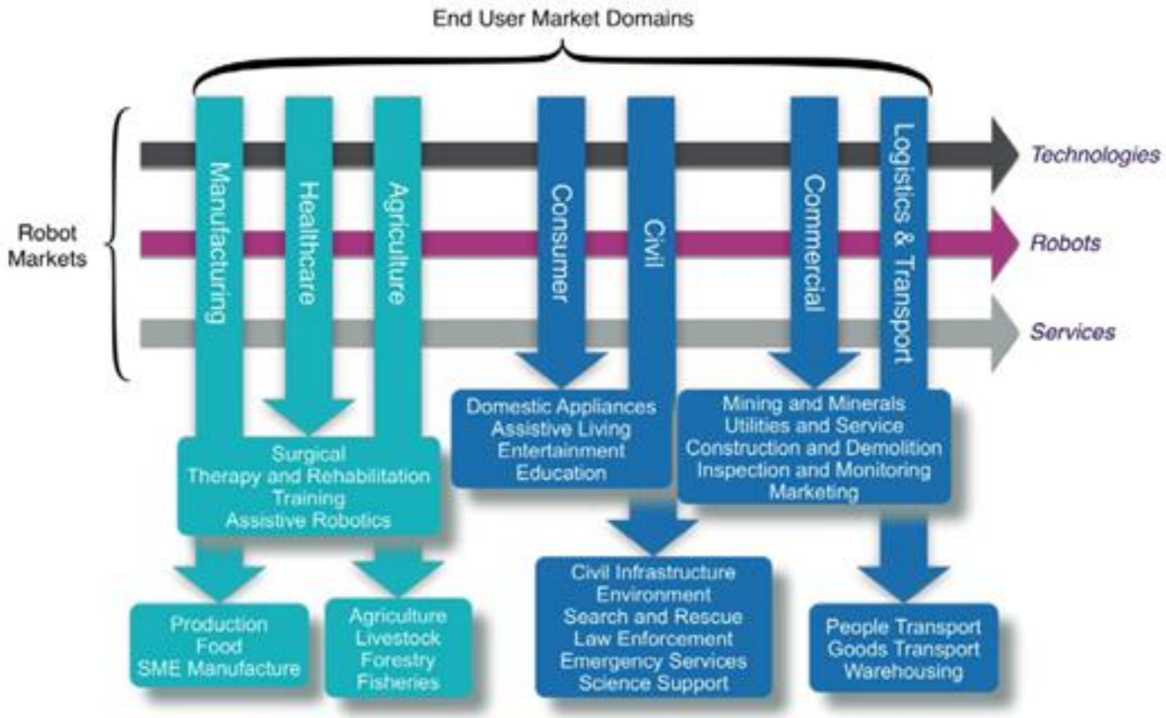

Fig. 2. Domains of robotics and robot markets, [12]

The **detriments** of using industrial robots are:

- *High initial investment.* Robots need a substantial amount of money, which must be invested in the beginning to build the production system. When integrating robots into the production system, costs must be taken into account, including the installation and configuration of the production system that uses robots as well, and, if necessary, further operations to reconfigure the production system in the future.

• *Robot installation expertise* can be very expensive. Robots require sophisticated operation, sophisticated maintenance and also, their programming is required, for all these things specialized personnel are needed. The introduction of a large number of robots into a production system can often be limited to the number of people with expertise who can handle implementation.

• *Permanent costs.* While industrial robots reduce some labor costs in production, but they need their own expenses, namely maintenance. Also, if robots are integrated into data networks, they must be protected from cyber attacks.

Figure 1 shows the developments of new industrial robots in the field of mechanical manufacturing. As can be seen, the number of new installations of industrial robots remained constant until around 2010, after which there is a significant increase that continues until the current period.

Figure 2 shows the field of robotics in correlation with the robot market in general. It can be seen from Figure 2 that the position occupied by industrial robots in the market is somewhat unique, but they actually represent about 60% of the market and the commercial value is over 80% of the robot market. Figure 2 shows that the robot market consists of 3 elements: technology, robot design and manufacture, and associated services.

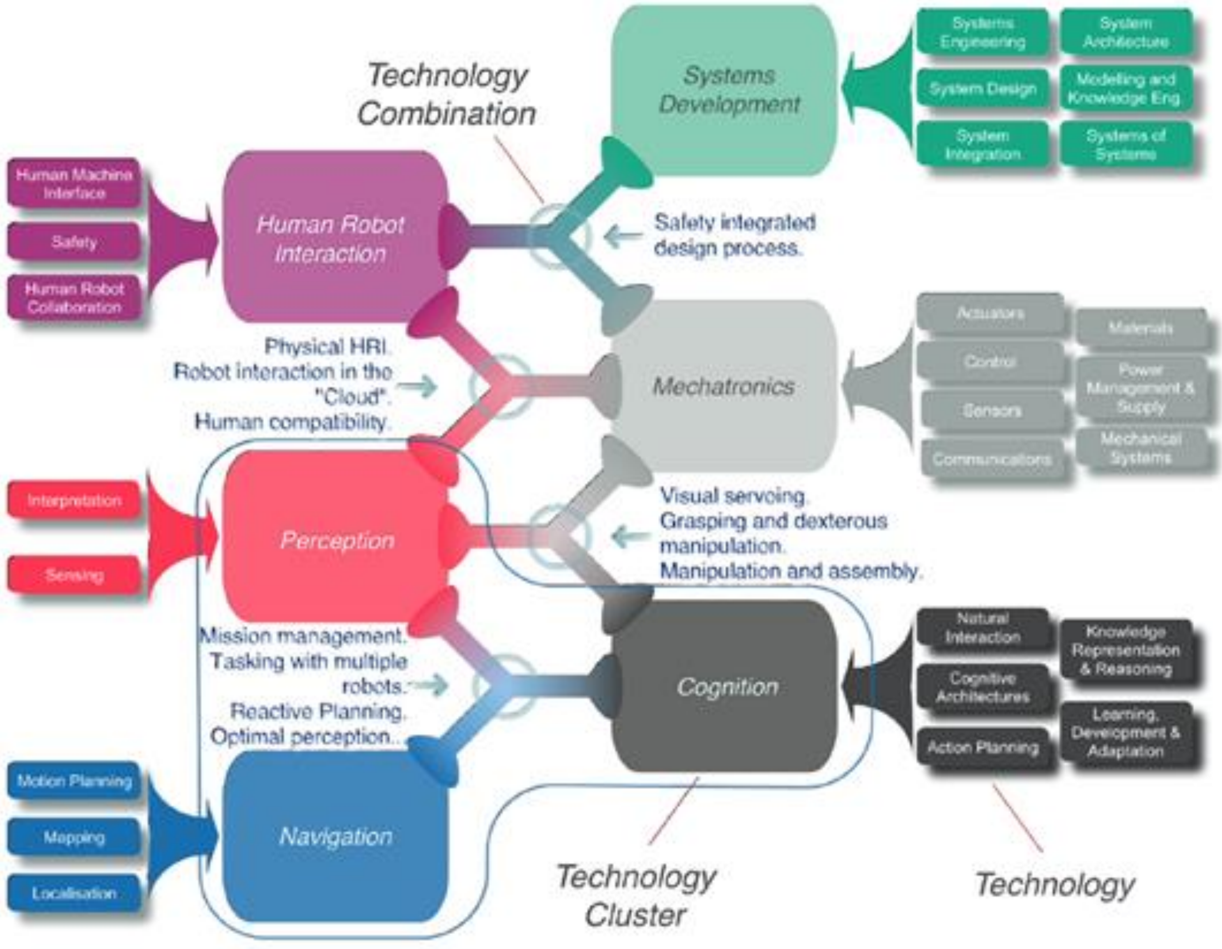

Fig. 3. Technologies used to develop a robotic system, [12]

If we look at the industrial robot as a mechanical system, depending on the application where the robot will be used, depending on the field and technology applied, we can analyze the performance of the entire system by defining levels that identify the skills and performance that the robotic system can have. System skills include: robot adaptability, cognitive ability, configurability, scalability, decision autonomy, reliability, interaction ability, manipulation ability, movement ability, and perception ability.

The development of a robotic system is very difficult, because many technologies are involved to produce a new type of robot. As seen in Figure 3, the technologies are divided into four clusters, each cluster being characterized by a specific purpose. We have: systems development, mechatronics, perception, navigation and knowledge, as well as cluster technology.

For each of these modules, the figure provides details on their components. As shown in Figures 2 and Figure 3 above, choosing the robotic system appropriate for the application in the future production system is much more

difficult than choosing a machine tool or any machine. The selection of industrial robots requires a special effort, as well as a great attention to the analysis of the parameters of the production system for which they must be designed.
The performance of any industrial enterprise can be measured in various financial parameters. Any introduction of a technical innovation in a production system, such as an industrial robot, can lead to a loss of money, if indeed economic and operational decisions have not been made correctly. Every proposed invention in the field of robotics must be financially tested, because the investment always involves a high risk. The evaluation techniques only aim at reducing uncertainties, but in the end the final decision belongs to the manager. Evaluation techniques can only reduce uncertainty, because there is no safe method to eliminate random elements that may occur during project implementation. Economic forecasts can take a wrong turn, for reasons beyond the control and knowledge of engineers / managers in the production system. All that can be done is to use the most advanced project evaluation techniques so that an investment project can prove to be financially rigorous.
There are several methods for evaluating investments, some of which are extremely simple while others are very complicated, which often do not necessarily lead to better results. A well-known fact is that all the results of the evaluation by the various existing techniques are based on the accuracy of the input data, which in most cases have to be roughly estimated or predicted. A good situation is when, and by a relatively simple calculation, it is estimated that the investments deserve to be made with a sufficiently large margin of accuracy to cover the approximate estimates.

2. ROBOT ECONOMICS

Regarding the economic and social analysis of the implementation of industrial robots, the following considerations can be made. The decision to implement industrial robots involves considerable changes in the company. The change within the company has a significant impact on workers, management and the financial situation. The introduction of industrial robots also has an impact on management. The location of industrial robots creates new job opportunities. For workers, it will be possible to operate with robots, resulting in the need to create robot service teams. The management of the company will have to retrain the workers individually, as well as to provide specialized personnel for the maintenance of the robots for quality control, and so on. In terms of the impact on the organizational structure, there are issues that arise in this structure. The efficiency of the robot installation will be determined by the success with which the respective changes were made in the organizational structure of the company [4].
For the introduction of industrial robots in the manufacturing process, there must be a financial justification of the cost associated with the implementation of the new work-equipment. It is clear that a complete and detailed cost-benefit analysis needs to be done in this circumstance. In the case of an investment in the robotization of a manufacturing process, an economic analysis can be performed from three points of view:

- determining the current investment;
- measuring the effect of investment on operations, costs and profitability;
- calculation of the benefit in relation to the current investment.

A checklist of economic factors cost versus savings can be made. The Table 1 [4] below shows this checklist.

Table 1. Checklist of economic factors: costs and benefits, [4]

Robot Costs		Robot Savings	
1	Price of the robot	1	Labor displaced
2	Special tooling	2	Quality improvement
3	Installation	3	Increase in throughput
4	Maintenance and periodic overhaul		
5	Operating power		
6	Finance		
7	Depreciation		

Hiring a worker in an enterprise depends on economic and social factors – and these factors are interdependent. As each job is analyzed, and the need for a new operator for a workstation, so must serious analysis be made for the purchase of new equipment or for the introduction of a new automation of the production process. For new equipment, such as machine tools, machinery, or industrial robots, there are several methods of analyzing the results of capital expenditures. A simple method also called the the payback method is enough to demonstrate the economic viability of an industrial robot [4].

$$\mathrm{P} = \frac{I}{L-E} \tag{1}$$

where: P = payback period [years], I = capital invested for the acquisition of the robot, L = total annual labor cost replaced by robot, E = maintenance cost for the robot.
The equation (1) presented above is the simplest method of financially evaluating the viability of a new project involving the robot. Usually, the payback period should be less than 3 years. If the repayment period is very short, no other valuation method is required. A more complex equation that takes production rate into account is the one below – equation (2) [4].

$$\mathrm{P} = \frac{I}{L-E\pm q(L-Z)} \tag{2}$$

where: P = payback period [years], I = capital invested for the acquisition of the robot and accesories, L = total annual labor cost replaced by robot, E = annual expense of the robot unkeep, Z = annual depreciation costs of associated equipment, q = production rate coefficient. It should be noted that the value of the coefficient q can be positive or negative, by comparing the activity of the robot to the human operator.
The analysis of the payback method works best when the general terms considered are short and the changes due to inflation or interest applied to the financing of the project are generally ignored in this analysis. For an example of industrial robot automation, the condition is that the payback period is short compared to the estimated life of the robot, so as not to be influenced by inflation or annual interest rates.
For an industrial enterprise, the financing of the automation plan is the main element in the realization of the project. In order to prove to banks and CFOs that they are worth investing in robotics, there are three main steps. (i) Every factor that could influence the financing of the robotization of the production process must be taken into account. (ii) Calculation of return on investment (ROI). (iii) Business case presentation.
Methods for determining the return on investment. There are various ways to calculate the return on investment used in industry. The simplest ROI seeks to calculate the return on investment for the business. For example, such an ROI calculation is performed with the formula (3) [7].

$$\mathrm{ROI} = \frac{(Gain\ from\ investment - Cost\ of\ investment)}{Cost\ of\ investment} \tag{3}$$

Other factors such as interest and inflation, costs and long-term profitability must also be included in the calculation of the return on investment. A deeper financial analysis also contains analysis tools, such as payback calculations. It is generally considered that the cash flow after investment exceeds that without investment before three years. That is, a smart value-added investment created by that investment must repay the cost of the initial investment before the end of the third year or sooner.
Figure 4 shows the steps to be taken to implement an automated production process with the help of industrial robots. Twelve distinct stages are involved which contain: understanding the process, technical analysis, defining the robot's specifications, designing the production simulation, selecting the industrial robot supplier, and actually designing the robot.
The next steps, from the installation of the robot (point 8) to the maintenance of the robot (point 11) are resource-intensive steps. Obviously, after a period of time it is necessary to reconfigure the production system, namely the replacement of the robot, the accessories, the parts supply systems, the grippers or the tools. The price of the robot is somewhere between 25 and 30% of the total cost of the assembly process. Most of the costs are found in the robot's programming, equipped with power supplies and grippers. This is shown in Figure 5.
Although the cost of programming the industrial robot cannot be easily estimated in its entirety, in fact it is the most expensive as well as the most unreliable link in the project implementation. The cost of programming involves the acquisition of CAD/CAM software applications dedicated to robotics, the acquisition of hardware, the acquisition of IT infrastructure, as well as the training of specialists in robot programming. If the implementation of collaborative robots is being considered, then the costs of dedicated sensors, intelligent shape recognition systems, or artificial intelligence applications can exceed the cost of a classic robot by several times.

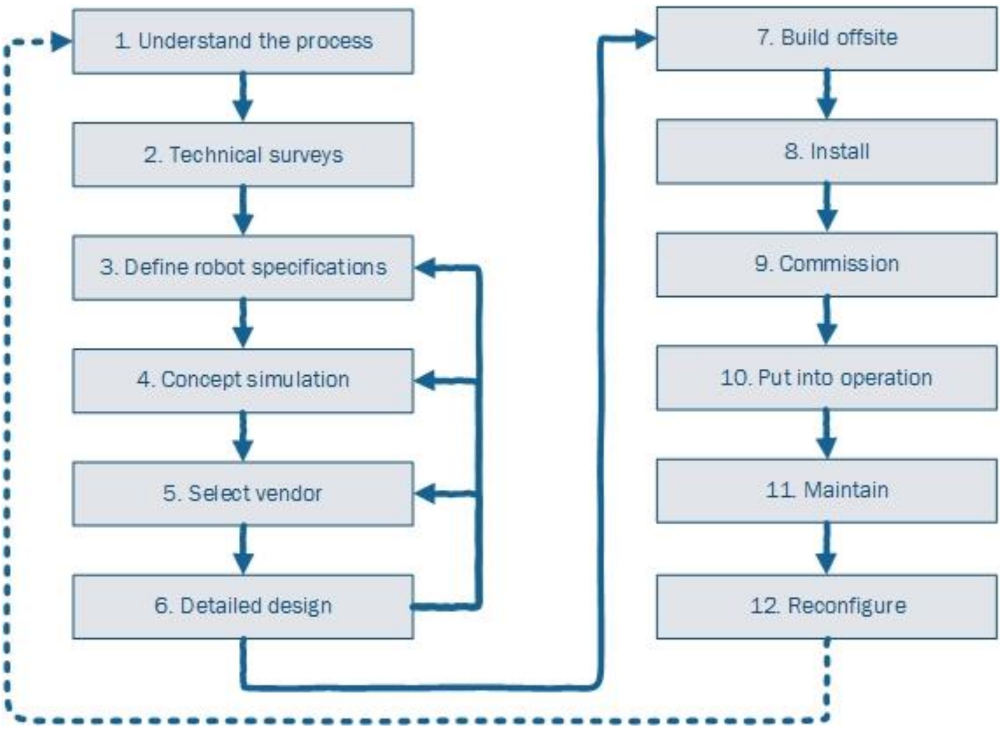

Fig. 4. Implementing an automated production process using of industrial robots, [7]

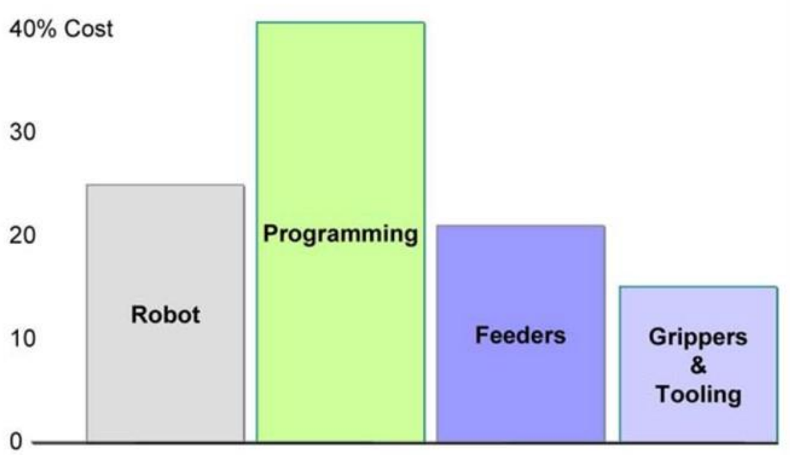

Fig. 5. The price of the robot compared to the other components that make up the automated production system, [6], (Source: Mauro Onori, KTH, Sweden, 2003, Automatic Assembly Systems/ B. Carlisie, Adept Technologies, USA)

3. AHP METHOD FOR INDUSTRIAL ROBOTS SELECTION

The method of the analytical hierarchy process (AHP) was first conceived by Thomas Saaty in the field of operational research. It is one of the most popular decision-making methods for many criteria. The methodology is based on two stages. In the first stage, the system of criteria used in decision-making is broken down hierarchically. The second stage involves moving from a direct assessment of the importance of the individual criteria and alternatives to the criteria to a peer review of the criteria and alternatives, [8].

For the AHP type analysis we used five types of industrial robots, manufactured by different companies. For the distinction, or rather the correct selection of the industrial robot we used the selection criteria as in Figure 6. The criteria were divided into three categories: level 1– overall objective, level 2 – group criteria and level 3 basic criteria. Regarding level 2 – Group Criteria, criterion C_1 represents 45%, criterion C_2 represents 20%, and criterion C_3 represents 35%.

Regarding the C_1 – Robot Performance criterion, we divided the basic criteria: Labor Displaced, Quality Improvement and Increase Throughput, so C_{11} represents 20%, C_{12} represents 40% and C_{13} represents 40%.

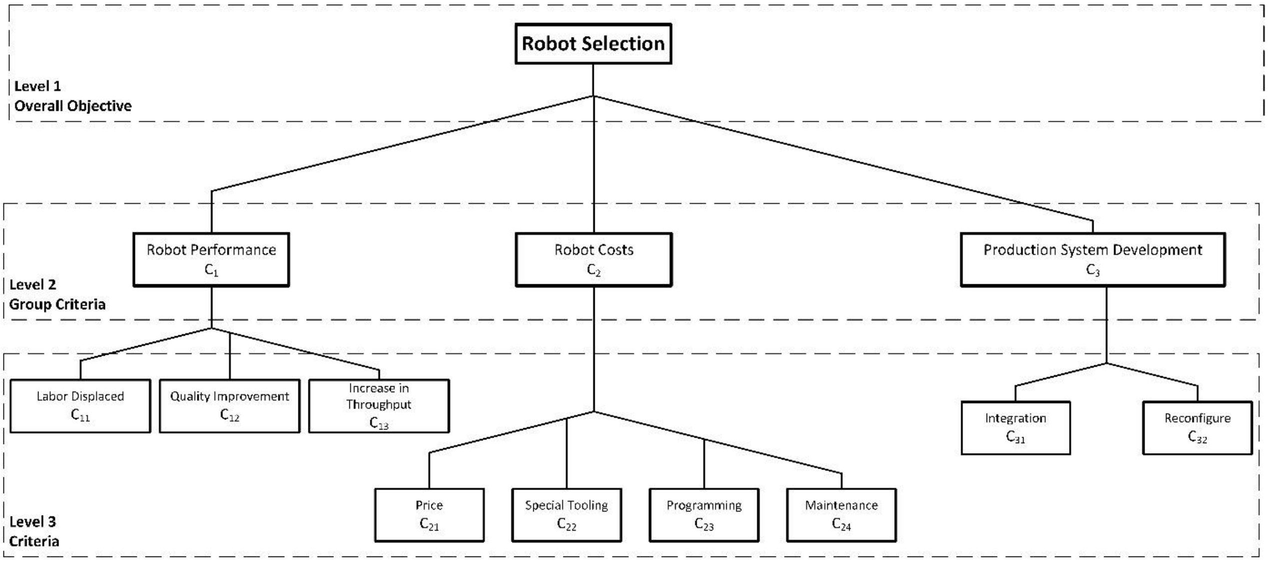

Fig. 6. Industrial Robot selection criteria

Of particular importance is the group criteria Robot Costs, which details the costs of implementing the robot. Regarding the C_2 criterion, we have the basic criteria C_{21} with a weight of 35%, the criterion C_{22} with a weight of 15%, the criterion C_{23} with a weight of 25% and the criterion C_{24} with a weight of 25%. Of major importance is the development of the production system, through the implementation of the industrial robot. For this, criterion C_3 has as components the basic criteria C_{31} (integration) with a weight of 60% and criterion C_{32} (reconfiguration of the production system) with a weight of 40%.

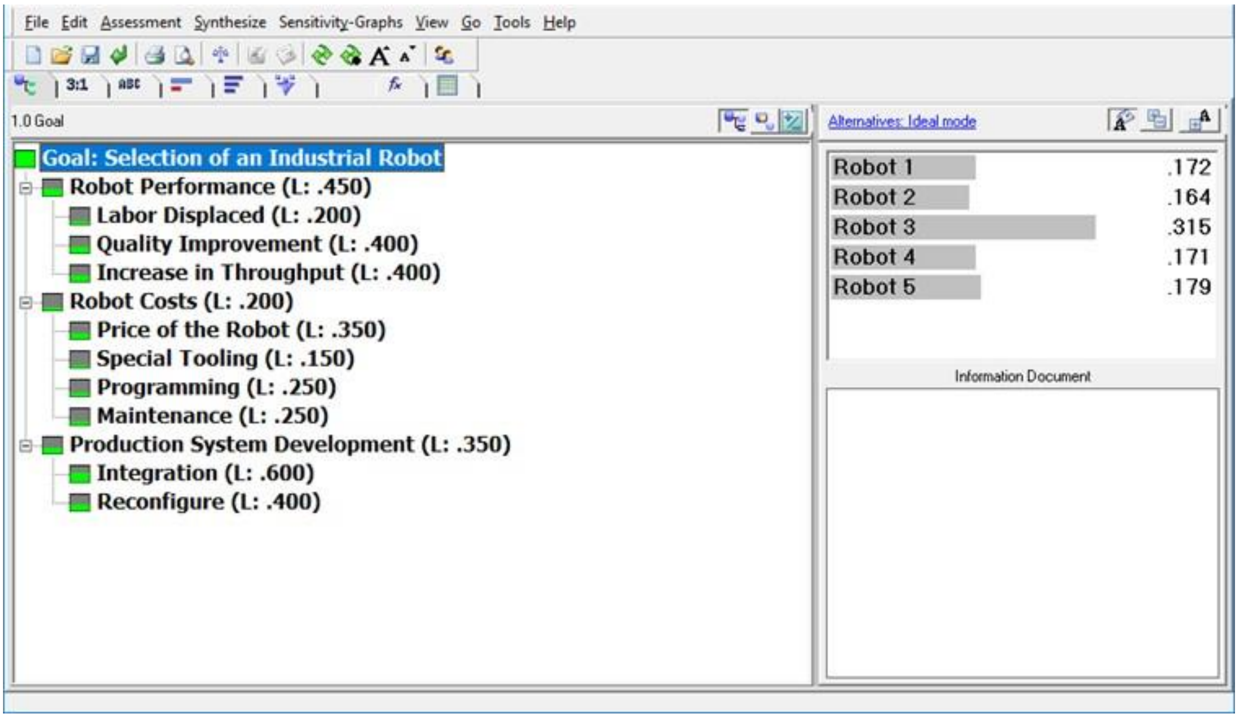

Fig. 7. AHP analysis for selection of an industrial robot

The values of all these weights are shown in Figure 7, AHP analysis for selection of an industrial robot. The value of the weights was determined from experience, following the analysis of the implementation of several types of industrial robots in the machine building industry.

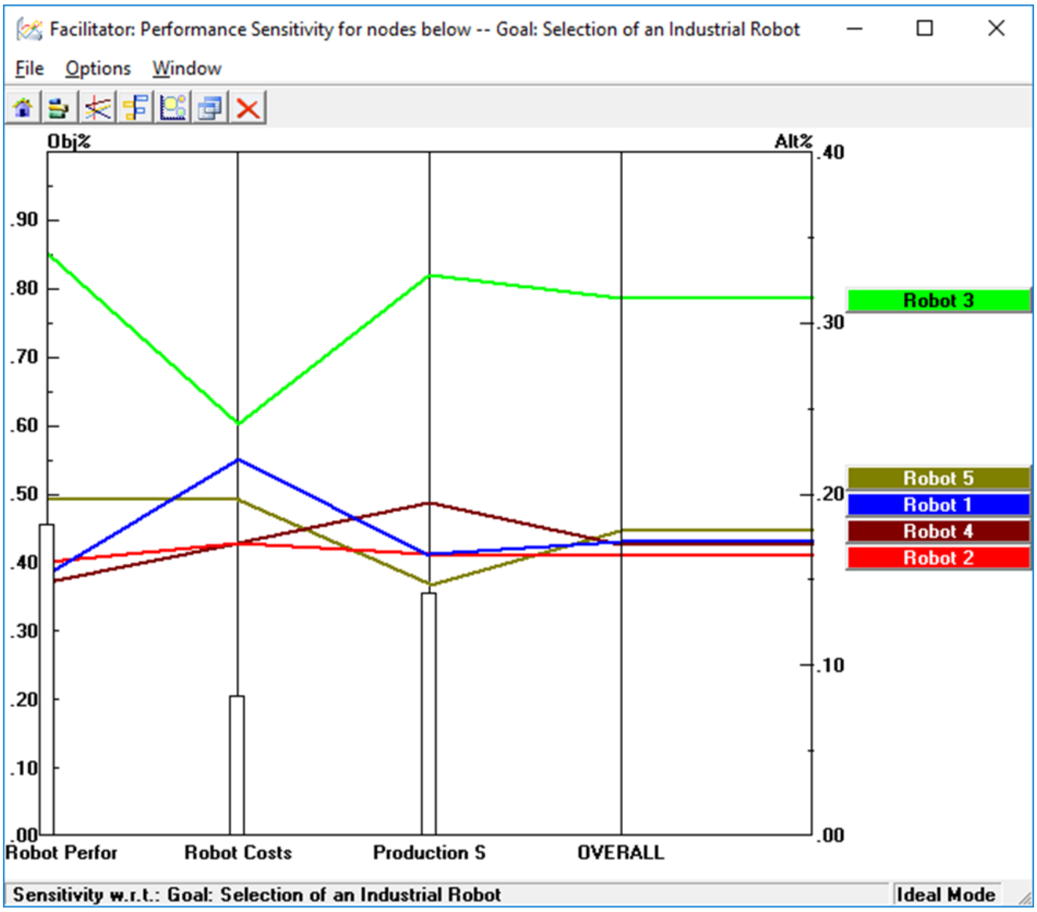

Fig. 8. Performance sensivity for nodes

The Expert Choice application [5] was used to conduct the study. Figures 8, 9 and 10 show the results of this analysis. Figure 8 shows the performance sensitivity for the nodes in Figure 7. Figure 9 shows the dynamic sensitivity for the same nodes, and Figure 10 shows the synthesis results for the selection of the industrial robot.

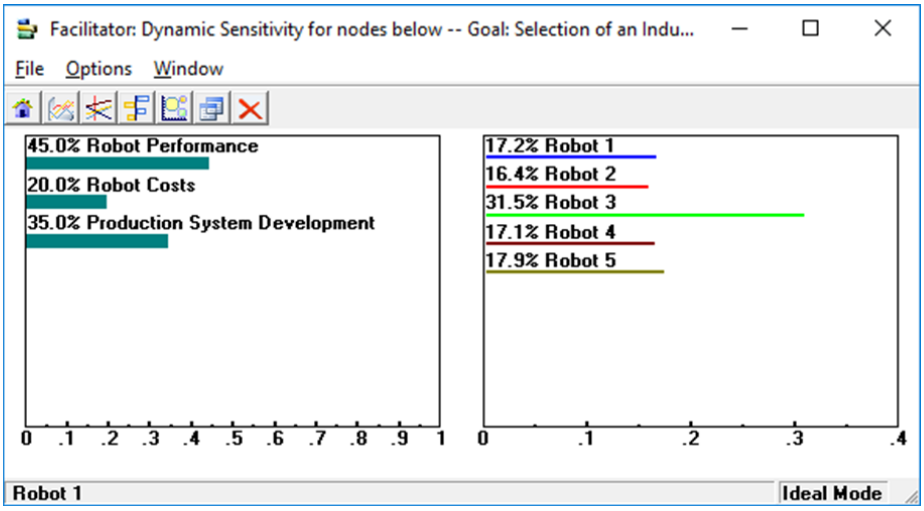

Fig. 9. Dynamic sensivity for nodes

As shown in particular in Figure 8, Robot 3 is the one to be selected, following the criteria presented. Although the robot has a cost price close to the other robots, the robot's performance is superior, but also the integration in the production system is much more beneficial.

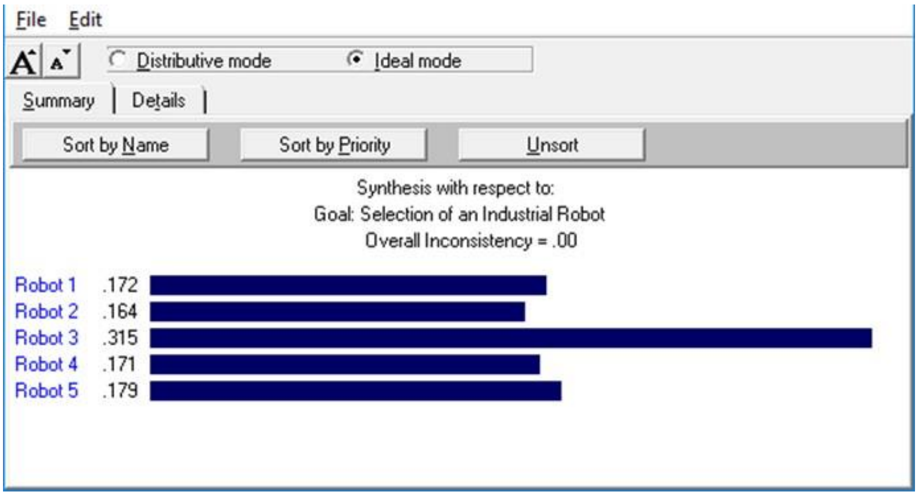

Fig. 10. Syntethis with respect to goal (selection of an industrial robot)

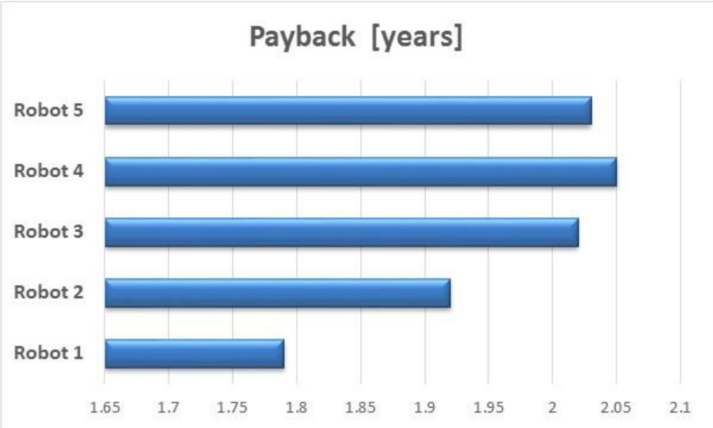

Fig. 11. Production rate payback (selection of an industrial robot)

Figure 11 shows the production rate payback, which was done using the calculation formula presented in this paper, respectively equation (2). The calculation was made for the same five industrial robots for which the AHP analysis was performed. As a working hypothesis, it was considered that each industrial robot must be integrated in the same production system. Also, for the payback calculation according to equation (2), the input parameters were considered identical, as those for the AHP analysis. It can be seen that there is a big discrepancy in the ranking of industrial robots following the ordering by the two calculation methods. The payback calculation can be considered a raw, primary analysis that does not provide much information other than financial information.

The managerial decisions of selection and introduction of the industrial robot in the production system must be taken through a complex analysis type AHP. The problem is whether the C_1… C_N criteria have been selected correctly. In addition to these things, the proportion of these criteria is also important, which is usually not presented in the literature – probably being considered a secondary element. Or precisely this proportion of the basic criteria leads to the choice of one robot to the detriment of another.

4. CONCLUSIONS

In this paper, the case of the selection of the most representative industrial robot for a certain existing production system was considered. For example, five types of industrial robots were considered, which belong to approximately the same class in terms of functional parameters, cost price, performance and integration with the existing production system. The case of the selection of the industrial robot based on the payback period formula – equation (2) was presented, which is a method closer to economists.

Using the more complex AHP method, and close to industrial managers and engineers, the same calculation was made for the same five industrial robots. The results can be seen by comparison in Figures 10 and 11. As can be seen, these analyzes give completely different results, indicating a different type of robot. It is obvious that the AHP analysis is the correct analysis, which indicates the desired result. For the industrial engineer, and for the visionary manager who is considering the further development of the production system, the AHP analysis is the correct one.

The success of any business must be measured in financial performance. Therefore, the most complex industrial robot introduced in a production system if it leads to financial losses is a mistake. Investing in industrial robots always involves a risk. The use of the AHP method reduces the uncertainty of the financial investment. On the other hand, this method requires a rich experience of the engineer or group of engineers involved in the implementation of the method.

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Received: March 05, 2022 / Accepted: June 15, 2022 / Paper available online: June 20, 2022 © International Journal of Manufacturing Economics and Management