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A PC-BASED MODEL FOR EVALUATION OF INVESTMENT IN MANUFACTURING EQUIPMENT

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ABSTRACT:

The investment in advanced manufacturing equipment must be evaluated on two levels, ie. a general technical investigation, and an in-depth technical and economical analysis if necessary. This is especially true for a country like South Africa where new technologies like robotics are relatively untried. It is therefore important to choose a suitable framework for both technical and economic analyses. This framework forms the foundation of the discussed evaluation model. For practical use, the evaluation and choice process is programmed for use on a PC.

OPSOMMING:

Belegging in toerusting vir gevorderde vervaardiging word gewoonlik op twee vlakke geevalueer, nl. 'n algemene tegniese ondersoek en 'n deeglike tegniese en ekonomiese ontleding, indien vereis. Dit is veral waar in 'n land soos Suid-Afrika waar nuwe ontwikkelings soos robotika nog relatief onbekend is. Dit is dus belangrik om 'n gepaste raamwerk te kies vir beide die tegniese en die ekonomiese ontledings. Hierdie raamwerk is die basis van die ontledingsmodel wat bespreek word. Om toepassing te vergemaklik, word die ontledings- en keuseprosesse geprogrammeer vir 'n mikrorekenaar.

1. INTRODUCTION

Any investment in manufacturing equipment needs to be evaluated on two levels. At first the investor has to do a general technical investigation into the technical feasibility of employing this type of equipment in his particular production facility. Following this evaluation and provided that a positive result was obtained, an in-depth technical and economic analysis is necessary. The investment in industrial robots and related equipment is analyzed along the same lines as normal capital equipment and will be used as a case study to illustrate the concept.

In general, in order to ascertain whether an acquisition is suitable for a given task and will be economical for that task, the potential buyer has to go through seven decision-making stages:

a.) Application identification.
b.) Needs analysis (pre-analysis).
c.) Acquisition identification.
d.) Technical analysis.
e.) Economic analysis.
f.) Post analysis.
g.) Decision and order placement.

Several recommendations exist for the seven different stages in the decision-making process. However, there is no user-friendly instrument to carry out this task. Obviously the more difficult stages are the technical and the economic analyses. Both of these have to be integrated in-to a software tool for practical usage on a PC.

2. MODEL FOR EVALUATION AND CHOICE OF ROBOT CONFIGURATION

2.1 General

There are different well-known ways to solve the defined task. Firstly, it depends largely on the complexity of the particular case. For simple cases and clear applications when there is a choice of robot configurations, it is often enough to use a suitable catalog to obtain detailed information from vendors and/or other users. An in-depth economic analysis can be sufficient for the final decision. For more complex cases and multipurpose applications, it becomes necessary to evaluate the possible technical alternatives from different angles. An estimate of the economic viability or a more intensive economic analysis can achieve the end result.

For technical analysis of simple cases, the building of the robot's family tree, following topology principles, can achieve a result relatively easily. The investigation of more complex applications demands wider consideration of various aspects. Here the utilization analysis of several technical and manufacturing parameters appear suitable. In certain cases the graphic method through use of a nomogram can bring fast as well as reliable results for the economic investigations. More complex applications demand more sophisticated methods. Break-even analyses and discounted cash flow methods were used in the developed model for the economic analysis [1].

2.2 Technical Analysis:

2.2.1 Approach: From the user's point of view, an evaluation model always requires at least a focused view of the particular manufacturing task. The best way to do this on a systematic basis, is to construct the technological requirements profile of this manufacturing task. A comparison with the appropriate technological capabilities profile of the technical equipment, gives a first orientation of its suitability. However, an application cannot be considered in isolation from the production realities, ie production structure, production equipment, man-power, etc. Therefore, these factors should play a major role in the evaluation process.

For sophisticated and capital intensive technical equipment, the reputation of the equipment supplier is also very important. The quality of his service and financial status can be decisive to the success of the investment.

The user therefore has to strive to find optimal technical equipment, in this particular case an optimal robot configuration, in relation to:

- Application suitability
- Utilization adaptability and
- Vendor reliability.

It is a basic principle in the industrial engineering field that a manufacturing process has to provide high productivity and good quality under acceptable economic conditions. So, the whole evaluation process from a technical point of view has to be seen critically through the prism of economic viability. Fig.1 illustrates this statement.

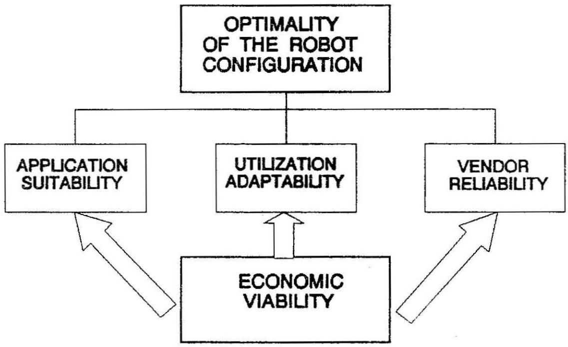

FIG. 1: EVALUATION MODEL FOR CHOICE OF A ROBOT CONFIGURATION FOR A PARTICULAR APPLICATION

For evaluation of technical objects, and also for objects of a non-technical nature, the Use Value Analysis method has been found to be very powerful [2]. Furthermore, it allows for the execution of the evaluation process on a PC. The first step is to find the significant attributes of the evaluated object which describes it well enough. Starting out from an overall aim, these attributes have to be expressed as aims in the direction which the evaluation is taking. From these aims, evaluation criteria can be derived, which concretise the aims. The evaluation criteria satisfy specific parameters and therefore, in turn, become arguments in the evaluation functions. The evaluation functions have to mathematically describe the technological reality with maximum truth. The evaluation result V_j expresses how the corresponding single aim A_j is achieved. This step depends largely on the specialised knowledge of the evaluator regarding the case under consideration. (Fig. 2).

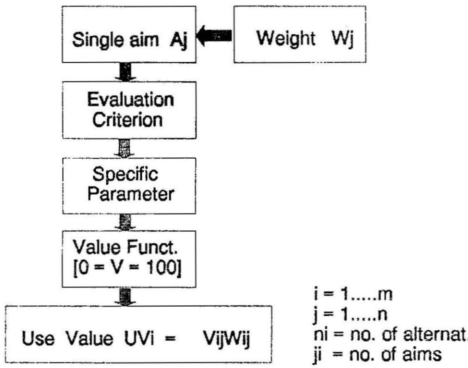

FIG. 2: STEPS IN THE EVALUATION PROCESS BASED ON THE USE VALUE ANALYSIS METHOD

It is clear that the different aims do not have equal importance. Thus it is necessary to weigh their contribution regarding a global aim. So every aim A_j receives a weight W_j. In this way the single use value U_j represents the multiplicative relationship between the value function result V_j and the weight W_j of its aim A_j or

$$U_j = V_j \cdot W_j$$

The final result is obtained through the sum of the single use values for the different aims. Or, for the i-st alternative between m alternatives evaluated after n aims, we have:

$$U_i = \sum_{j=1}^{n} V_{ij} W_j . \quad (i = 1 \ldots m;\ j = 1 \ldots n)$$

2.2.2 Aim Hierarchy: The overall aim of the evaluation model will be to choose an optimal robot configuration for a particular application. However, the optimality cannot be discussed in general terms. It always relates to a concrete situation and embodies a defined point of view. Therefore, the defined overall aim must be divided into the following three group aims:

- Good suitability to the manufacturing task (application)
- High adaptability to the manufacturing conditions (utilization)
- High reliability of the potential supplier (vendor).

Every one of these three group aims can be sub-divided into separate single aims. To obtain an answer to the first group's question: "How suitable is the robot configuration to the application?", it is necessary to compare the application's requirements and the robot's capabilities. The user has to strive for the maximum usage of the robot's capabilities, because every unused function places an unnecessary burden on the economic viability of the application. Thus, the user has to aim at:

A1 : Effective use of Work Envelope
A2 : Effective use of Main Degrees of Freedom
A3 : Effective use of Dynamic Qualities of Robot
A4 : High usage of Payload Capacity
A5 : Effective use of Positioning Accuracy
A6 : Effective use of Repeatability
A7 : Effective use of Memory Capacity.

The second group aim concerns the manufacturing conditions of the user, or: "How adaptable is the robot configuration to the workshop environment?". Here the user has to estimate how the robot behaves regarding flexibility and availability (reliability, safety, manpower). Therefore, the user has to ensure a fast change-over to other manufacturing tasks (time flexibility) and also a large application variety (function flexibility). The function flexibility is directly related to the end-effector, or: how free is the wrist, how wide are the grippers designed, etc. Furthermore, the "communications" feasibilities can play a very important role. A robot set-up is normally a capital intensive investment. Therefore, the user has to strive for a high production availability of the robot. He has to be in a condition to quickly discover the reasons for a fault or failure or he wants his equipment to work a long time without failure. Finally the user expects a high safety factor from his acquisition regarding itself or other equipment because of the danger of possible collisions and defects, but also regarding other operations or people. It therefore follows that the second group aim can be divided into the following single aims:

A8 : Rapid Change-over
A9 : Effective use of Wrist Degrees of Freedom
A10 : Multifunctional usage of Grippers
A11 : High Communications Capabilities
A12 : Good Diagnostic Capabilities
A13 : High Reliability
A14 : High Safety.

The third group aim investigates the manufacturing and business relations between user and vendor. The latter's professionalism, loyalty and economic stability has a marked influence on the success of the acquisition. Firstly it is necessary to ensure close co-operation between the vendor's sales department and technical department of the user. Thus the vendor has to be more of an adviser, not simply a supplier or seller. A highly professional and fully comprehensive specification must be presented to the user. A list of necessary user activities including a time schedule must also be discussed with him. All these steps in the pre-sale service should contribute towards an installation in the shortest possible time under the vendor's supervision. Availability of high quality training on the part of the vendor for operator and maintenance personnel is also to be expected. The reaction of the vendor in emergencies, the availability at all times of spare parts as well as the quality of vendor service personnel, are further important aspects. Finally the reputation of the vendor together with his financial condition rounds off the overall picture of the vendor.

Thus the third group aim can be divided into the following three separate aims:

A15 : High Quality of Sale Activities
A16 : High Quality of Service Activities
A17 : High Stability of the Vendor's Company.

For the weighting in this technical orientated evaluation model, the assumption is made that for the user, all three aspects, represented by the three group aims, are equally important. Therefore all 17 aims have the same starting points (the same basic conditions). To have the whole evaluation process on the same basis as the value functions, it is necessary to define the condition

$$\sum_{j=1}^{17} W_j = 1$$

Based on an estimate for the general importance of several hardware/software variables of industrial robots, vendor performance variables as well as robot's internal adaption variables given in [3], can be shown by the weights W_j of the several aims A_j on a 10 point scale system as well as their values under the above sum condition.

2.2.3 Results Interpretation: For clear and direct conclusions, graphic exhibits like histograms are very suitable and are preferred above mathematical results. These diagrams can clarify the following questions:

(a). Where are the weaknesses of every robot configuration alternative?
(b). What typifies these weaknesses?
(c). What can the user do to improve the technological picture?
(d). Which (potential) application is more suitable?
(e). Which robot configuration is most suitable (optimal) for the given technological reality from a technical point of view?

A further important conclusion can be ascribed to the vendor regarding the eventual improvement of his product's capability. It is remarkable how the weights influence the final result.

2.3 Economic Analysis:

To use a discounted cash flow method, all the significant costs that are likely to result from the investment should be included. The economic impact should be measured over the total life cycle of the proposed system. Economic factors estimated for each of the candidate configurations as well as for the existing process, should be taken into account. Economic impact will occur in three areas:

(a). Plant and equipment.
(b). Operations and maintenance.
(c). Product manufactured.

Most of the important economic factors are considered in the developed model like cost of engineering and design; cost of modification of existing equipment and buildings; installation cost; production down time; etc.

Savings and benefits are also considered and include indirect labour cost saving; floor space reduction; scrap and rework reduction and material savings.

The main parameters used under different sections are for example the number of robots, the number of shifts, the number of robots that can be served by one operator, and others.

To test the reliability and sensitivity of the model, some of the important and dominant parameters were varied between limits and the changes in the nett present value observed. The following parameters were identified as the sensitive parameters:

a) Number of robots and number of shifts.
b) Number of robots that can be served by one operator.
c) Labour yearly inflation rate.
d) Opportunity cost rate.
e) Scrap rate.
f) Cycle time.
g) Value added.

The model calculates the number of robots to achieve the production for maximum demand in the planning period. With the number of robots known, the model calculates the number of shifts needed for the year's production to achieve the demand for that year. As a result, the final inventory is calculated to determine the shortage cost or the carrying cost of the finished product.

2.4 Solution possibilities for the evaluation task:

In general it is possible to solve the evaluation problem manually with the aid of a scientific calculator because it deals with relatively simple equations. For a broader interpretation of the results, this is not enough. A graphic diagram of the results would also be very difficult and awkward to prepare.

The interactive execution of the evaluation on a personal computer is much more rational. In this way a lot of benefits are made possible:

- fast and precise execution of the evaluation process;
- easy and clear exhibition of the results;
- elegant execution of simulation calculations and comparisons;
- best record of the results;
- direct relation between technical and economic model;
- the expansion of the whole evaluation model to a software tool for the decision-making process in robot configurations.

The program has been written for use on a PC of type IBM PC/XT, AT and compatibles. Successive simulation runs can be especially useful because the influence and sensitivity of the different parameters can be established. This is essential for the design and implementation of several technical or organisational changes.

2.5 Discussion of the evaluation model:

In total, there are about 100 input data sets for both technical and economic evaluations. All input data sets are relatively easily accessible or ascertainable. The calculation of the results with a scientific calculator takes about 3 hours. However, the documentation of the results, their interpretation, discussion and recording is very inconvenient. Therefore, the execution of the evaluation on a PC has to be considered as the "normal" case. The whole evaluation process including the accurate documentation of results, reliability and quality is done in a few minutes.

Finally it can be said that the work volume for the evaluation process is directly related to the matter of data collection, recording and presentation. Most input data sets can be inferred from several documents like manuals, plans etc. The work volume can be very small if the user has different data bases already available. Therefore the question of the work volume depends largely on the information level of the user company and particularly on it's ability to solve its own information problems.

The question of the reliability of the results is very important. Regarding the technical model, two principal error groups are usual. The first group contains errors which are person dependant. This is so for example if the evaluation criteria are not independent of each other. Other errors are caused by unsuitability of the value functions.

Therefore, much attention has been devoted to the construction of the aim hierarchy. The various aims have been defined after a thorough verification that every evaluation criterion can be characterised through a clearly ascertainable variable. The proposed value functions are based on logical relationships.

The errors of the second group emerge from the logic of the evaluation method. They occur if the specific parameters are not unequivocal. For this application case, this error group is not applicable.

The weighting contributes to objectivity and therefore to essential raising of the statement reliability. It is advantageous if the weights are laid down not by one person, but by an expert team representing the practical conditions of the company concerned.

The discounted cash flow method which was used in the economic model, considers both the opportunity cost of an investment and the longevity of the project's cash flow. Some of the more popular ways of discounting the cash flow are the nett present value, equivalent annual cost and internal rate of return. When used properly, these are the best methods to obtain consistent and financially sound solutions. In this case the nett present value variant was used. A planning horizon of eight years was assumed because this seemed to be an acceptable technological life for hi-tech equipment like industrial robots. The model calculates a cash flow table over eight years and then reworks all costs and savings over the same period to an equivalent nett present value and an annuity. The nett present value ratio is then expressed for example per number of parts produced and per robot shift. However, the reliability of the results depend mostly on the care and comprehensiveness with which the necessary data is collected and recorded. This is also a general requirement in the solution of all information and economic problems. Otherwise it is clear that the raising of the statement reliability directly causes rise in work volume. This fact has to be taken into consideration especially in complex applications.

3. SUMMARY AND CONCLUSIONS:

In this paper, possibilities for choice of a robot configuration for a particular application were discussed. Starting from the chained steps of the decision-making process, an evaluation model for technical analysis of robot configurations was developed. Special attention was given to the building of the aim hierarchy. Therefore related technological realities were thoroughly researched and described mathematically through evaluation functions. A results interpretation provides a connection with the economic model, which was briefly discussed. A discussion of the whole evaluation model with regards to work volume and results reliability ends this study. Possible uncertainties are indicated.

The evaluation model discussed in this paper provides the technical manager with a very useful solution to robot installation problems. It allows for "what-if" type testing of many possible scenarios and parameters over a specified planning horizon. An analysis shows that robot installations can be profitable for normal production reasons like scrap reduction and the resulting lower production and inventory requirements, and not only on the basis of the replacement of direct labour.

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