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PRIORITY SETTING OF INDUSTRIAL ROBOTS WORKING PLACES AND OPERATIONS IN SHIPYARDS

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ABSTRACT

The great participation of direct human work characterizes today's shipbuilding industry. The actual status in development of science and technology makes possible the replacement of humans with industrial robots in a great number of these working places.

The strategy of industrial robots introduction in shipyards has to be adapted to existing working conditions, and introduction has to be done gradually.

The paper deals with a new method for priority setting of industrial robots working places and structures in shipyards, based on the analytic hierarchy process. The numerical measure of priority of working places is based on the comparative pairwise judgments of social, psychological, technological, technical, safety, productivity and economical factors on different working locations. After the priority working places and priority working operations are chosen, the priority structures of adequate industrial robots has to be determined according to their geometric, kinematic, dynamic and control characteristics.

KEY WORDS: Industrial robots, shipbuilding industry, priority setting, analytic hierarchy process.

1. INTRODUCTION

The use of industrial robots in production operations is a relatively new aspect of manufacturing engineering. The development and implementation of robots applications generally follows the same basic sequence as any other manufacturing process. However, the robot's unique combinations requires some special considerations for succesful application |7|.

The use of industrial robots in shipbuilding industry is a quite new aspect, so there is not much experience from this field and existing data are very poor and unattainable |1,2, 3|.

Today's shipbuilding industry is characterized with great participation of direct human work on hard, dangerous and fatiguing jobs. The actual status in development of science and technology makes possible the replacement of humans with industrial robots or with other automatic machines in a great number of these working places. The operations of surface cleaning, surface protection, coating, painting and welding are surely the operations which can be succesfully done by today's industrial robots.

The strategy of industrial robot introduction in shipyards has to be adapted to existing working conditions, and introduction has to be done gradualy. The experience from other fields |4, 7| confirms that the first robot installed at any location is the most important, and this fact was our motto throughout entire project and investigation. Our efforts in this project was oriented in these directions:

- to become thoroughly familiar with working locations and operations,
- to include workers and foremans in project and so to get their ideas and make them feel that they are part of the action,
- to get management to back ourselves up, because total commitment by everoyone is necessary for success,
- to be honest in answering questions from the workers,
- to provide comprehensive maintenance training of sufficient personnel to cover all shifts and give them the tools necessary to do their jobs,
- to use our imagination and consider alternatives to the usual floor mounting of robots, or, not to simply imitate a man with a robot because there may be the better ways,
- to start with the simple applications (corollary of Murphy's law says "If you have 50%-50% chance of success, there is a 75% chance of failure".)

It is obvious that the success of first robot application in shipyard is dependent on the efforts made to apply the above considerations. Anything less than maximum dedication to all of the above could result in some degree of failure.

2. THE ANALYTIC HIERARCHY PROCESS

Industrial processes today seems to consist of many complex nonlinear problems which feed one another. Every industrial plant can be described as a complex system of interacting factors. It is a network of factors whose causes and effects are not easily identified. Nearly all of us have been brought up to believe that clear headed logical thinking is our only sure way to face and solve complex problems. Our feelings and our judgments must be subjected to the rigorous test of deductive thinking. But experience suggests that deductive thinking is simply not natural, so we have to be trained, and for a long time, before we can do it well.

It is generally believed that because the industrial processes are so complicated, that to solve real problems in such a processes, we need to think in a complex way. In fact, we probably do not need a more complicated way of thinking. Most of us have difficulty examining even a few ideas at a time. We need an approach to organize our problems in complex structures but which also allow us to think about them one or two at a time. In other words, we need a conceptually simple and decisionally robust approach, so that we can use it easily and that it can handle real systems complexities.

The Analytic Hierarchy Process (AHP) derived by Saaty |5,6| is such a problem-solving framework. It is a systematic procedure for representing the elements of any problem. It organizes the basic rationality by breaking down a problem into its smaller constituent parts and then calls for only simple pairwise comparison judgments to develop priorities in each hierarchy.

The Analytic Hierarchy Process does not insist on explanations. It provides a comprehensive framework to cope with the intuitive, the rational and the irrational in us all at the same time. It is a method we can use to integrate our perceptions and purposes into an overall synthesis. The Analytic Hierarchy Process does not require that judgments be consistent or even transitive. The degree of consistency of the judgments is revealed at the end of the process.

The Analytic Hierarchy Process consists of eight steps. Particular steps may be emphasized more in some situations than in others, and interaction is generally necessary:

1. Define the problem and determine what you want to know.

2. Structure the hierarchy from the top (the objectives form a general viewpoint) through the intermediate levels (criteria on which subsequent levels depend) to the lowest level (which usually is a list of the alternatives).

3. Construct a set of pairwise comparison matrices for each of the lower levels-one matrix for each element in the level immediately above. An element in the higher level is said to be a governing element for those in the lower level since it contributes to it or affects it. In a complete simple hierarchy, every element in the lower affects every element in the upper level. The elements in the lower level are then compared to each other based on their effect on the governing element above. This yields a square matrix of judgments. The pairwise comparisons are done in terms of which element dominates another. These judgments are then expressed as integers (see Table I for judgment values). If element A dominates over element B, then the whole number integer is entered in row A, column B and the reciprocal (fraction) is entered in row B, column A. Of course, if element B dominates element A then the reverse occurs. The whole number is then placed in the B, A position with the reciprocal automatically being assigned to the A, B position. If the elements being compared are equal, a one is assigned to both positions.

4. There are n(n - 1)/2 judgments required to develop the set of matrices in step 3) (remember, reciprocals are automatically assigned in each pairwise comparison).

5. Having made all the pairwise comparisons and entered the data, the consistency is determined using the eigenvalue. ($Aw=\lambda_{max}\,w$ is determined. The consistency index then using the deparature of λ_{max} from n compared with corresponding average values for random entries yielding the consistency ratio CR).

6. Steps 3), 4), and 5) are performed for all levels and clusters in the hierarchy.

7. Hierarchical composition is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

8. The consistency of the entire hierarchy is found by multiplying each consistency index by the priority of the corresponding criterion and adding them together. The result is then divided by the same type of expression using the random consistency index corresponding to the dimensions of each matrix weighted by the priorities as before. Note first that the CR should be about 10 percent or less to be acceptable. If not, the quality of the judgments should be improved, perhaps by revising the manner in which questions are asked in making the pairwise comparisons. If this should fail to improve consistency, then it is likely that the problem should be more accurately structured; that is, grouping similar elements under more meaningful criteria. A return to step 2) would be required, although only the problematic parts of the hierarchy may need revision.

It is important to note thate if we actually had the exact answer in the form of hard numbers, we would normalize these numbers, form their ratios as described above, and solve the problem. We would get the same numbers back, as should be expected. On the other hand, if we did not have the firm numbers we could estimate their ratios and solve the problem.

TABLE I. SCALE OF RELATIVE IMPORTANCE

Intensity of Relative Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another.
5	Essential or strong	Experience and judgment strongly favor one activity over another.
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgment	When compromise is needed.
Reciprocals of above non-zero numbers	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared to i.	

3. PRIORITY SETTING OF SURFACE PROTECTION WORKING PLACES AND OPERATIONS

The operations of surface protection in shipyards are very important, hard, dangerous and fatiguing jobs. For these reasons we chose surface protection operations for the first application of industrial robot in shipyard.

The problem was to decide which working places and operations in surface protection to hose for the first application of industrial robot. The first step is the decomposition of the problem as a hierarchy.

In the first level is the overall goal: "The right first application of industrial robot in shipyard. In the second level are seven factors of criteria which contribute to the goal. In the third level are the four candidate locations which are to be evaluated in terms of the criteria of the second level (Fig.1.).

Factors of criteria are:
- sociological factor, fluctuation (SOC),
- psychological factor, motivation (PSY),
- technological factor (TCO),
- technical factor (TCI).
- workers safety factor (SAF),
- productivity factor (PRO),
- economical factor (ECO).

Candidate locations are:
- iron sheet preparation (loc.A)
- pre-equipping on supports (loc.B),
- slide way (loc.C),
- equipping shore (loc.D).

After the inquiring of seventeen workers, five foremen and authors, the pairwise comparison matrix of factors of criteria occurs (Table II).

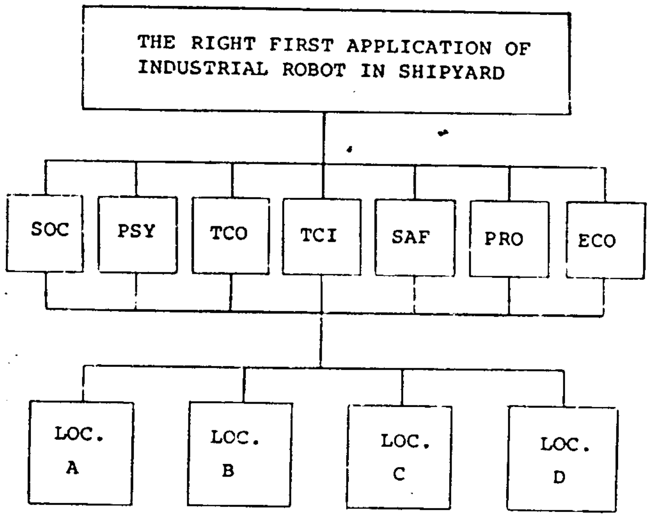

Fig.1. Decomposition of the problem into a hierarchy

Table II Pairwise comparison matrix for level 2

	SOC	PSY	TCO	TCI	SAF	PRO	ECO	PRIORITY VECTOR
SOC	1	1/2	1/5	1/5	1/8	1/6	1/3	0,027
PSY	2	1	1/3	1/5	1/4	1/3	1/2	0,049
TCO	5	3	1	2	1/4	1/3	4	0,140
TCI	5	5	1/2	1	1/4	1/2	2	0,116
SAF	8	4	4	4	1	5	7	0,422
PRO	6	3	3	2	1/5	1	3	0,185
ECO	3	2	1/4	1/2	1/7	1/3	1	0,060

CI = 0,099 CR = 0,075 λ_{max} = 7,595

Table III shows four (of seven) matrices of the locations and their local priorities with respect to the elements in level 2.

Table III Matrices of the locations for safety, productivity, technological and technical factors of criteria

SAFETY

	A	B	C	D	PRIORITY VECTOR	
A	1	1/5	1/7	1/8	0,042	CI = 0,067
B	5	1	1/3	1/5	0,129	CR = 0,074
C	7	3	1	1/3	0,270	λ_{max} = 4,201
D	8	5	3	1	0,559	

PRODUCTIVITY

	A	B	C	D	PRIORITY VECTOR	
A	1	1/2	1/3	1/2	0,120	CI = 0,081
B	2	1	2	4	0,435	CR = 0,090
C	3	1/2	1	3	0,307	λ_{max} = 4,243
D	2	1/4	1/3	1	0,139	

TECHNOLOGICAL

	A	B	C	D	PRIORITY VECTOR	
A	1	1/2	1/3	1/2	0,120	CI = 0,072
B	2	1	2	3	0,412	CR = 0,079
C	3	1/2	1	3	0,317	λ_{max} = 4,215
D	2	1/3	1/3	1	0,150	

TECHNICAL

	A	B	C	D	PRIORITY VECTOR	
A	1	1/4	1/4	1/4	0,072	CI = 0,072
B	4	1	3	3	0,494	CR = 0,079
C	4	1/3	1	2	0,253	λ_{max} = 4,215
D	4	1/3	1/2	1	0,180	

The next step is to apply the Principle of Composition of Priorities. The resulting vector of global priorities of observed locations is:

$$\begin{vmatrix} A \\ B \\ C \\ D \end{vmatrix} = \begin{vmatrix} 0,0729 \\ 0,2764 \\ 0,2889 \\ 0,3608 \end{vmatrix}$$

Now the same procedure has to be applied for priority setting of microlocations on each location (except location A which has extremely low global priority index).

At this point the goal is to derive optimal technical structure of industrial robot for each microlocation and for particular operation. The new factors of criteria are:
- geometry of working place (shapes and dimensions) (GEO),
- approachability of working place (APP),
- safety of application of industrial robot (SAF),
- productivity (PRO).

Our investigation leads towards the pairwise comparison matrix of these new factors of criteria. After that on each location the microlocations are defined (for instance, on location D the microlocations are: plating over sea level deck, store places, tanks, hull blocks, peak tanks, super structure, engine room, etc.).

All microlocations are evaluated after pairwise comparison in terms of the defined criteria. The hierarchy sequence of microlocations in terms of the first right application of industrial robot in surface protection jobs in shipyard is evaluated by weighting the priority vectors of microlocations with elements of the global priority vector of locations. (Fig.2., Table IV)

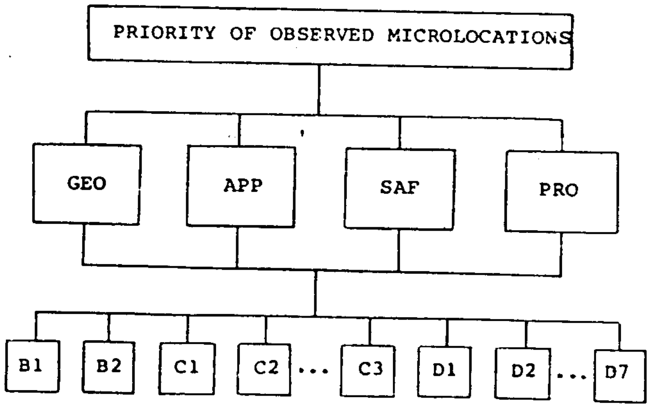

Fig.2. Decomposition of the problem into a hierarchy

Table IV Pairwise comparison matrix for the new factors of criteria

	GEO	APP	SAF	PRO	PRIORITY VECTOR
GEO	1	1/3	3	3	0,250
APP	3	1	5	4	0,529
SAF	1/3	1/5	1	4	0,146
PRO	1/3	1/4	1/4	1	0,075

CI = 0,119

CR = 0,133

λ_{max}=4,358

After applying the Principle of Composition of Priorities the resulting vector of priorities of observed microlocations is:

B1 - double hull blocks	0,0215
B2 - chimneys	0,0914
C1 - plating under sea level	0,1416
C2 - plating over sea level	0,1122
C3 - engine room	0,0488
C4 - pump rooms	0,0308
C5 - double hull blocks and peak tanks	0,0153
C6 - double hull blocks for fuel and water	0,0097
D1 - plating over sea level	0,1625
D2 - deck	0,1085
D3 - store places	0,0777
D4 - tanks	0,0327
D5 - peak tanks	0,0156
D6 - engine room	0,0358
D7 - super structure	0,0831

Now, we have to define factors of criteria for priority setting of working operations on each microlocation. The appropriate factors of criteria are:
- type of robot kinematic chain (open or closed),
- type and power of robot actuators,
- robustness of robot structure,
- safety.

Alternative operations on each microlocation are sand blasting, grinding and painting. It means that there are 45 possible alternatives (three on each of 15 microlocations).

After deriving the vectors of priorities of factors of criteria for each microlocation, the weighting factors of the operations occur. Applying the Principle of Composition of Priorities the resulting vector of global priorities of working operations on observed microlocations was derived. The element D1P of this vector (location D1 for painting, or in other words, painting of plating over sea level at equipping shore) is the most significant one. The conclusion is obvious: the right first application of industrial robot on surface protection jobs in shipyard "Split" has to be on painting the plating over sea level at equipping shore.

The resulting vector of global priorities with 45 elements give the rang-list of priorities, and after accepting this philosophy from shipyard management, the priority structures of adequate industrial robots have to be determined.

4. CONCLUSION

The conception of industrial robot introduction in shipyard has been derived. The Analytic Hierarchy Process has been used as a complex problem-solving framework. The operations of surface protection have been analyzed. The numerical measures of priority of observed locations, microlocations and operations were derived. The workers, foremen and authors have been working together throughout the entire project and the results seem to be objective and real.

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