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THE PRIORITY MANIPULATORS CHOICE FOR WELDING 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 grea number of these working places.

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

The paper deals with a new method for priority setting of industrial robots working places and structures for welding operations 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 are suggested according to their geometric, kinematic, dynamic and control characteristics.

KEY WORDS: Industrial robots, shipbuilding industry, welding operations, priority setting, Analytic Hierarchy Pro

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 |10|.

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 |1,2,3,5,6,7|.

Today's shipbuilding industry is characterized with great participation of direct human work on hard, dangerous and fatiguing hobs. 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 gradually. The experience from other fields |4,10| 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 foremen 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 to commitment by everyone is necessary for success,
- to be honest in answering questions from the work
- to provide comprehensive maintenance training of s ficient staff to cover all shifts and give them tools necessary to do their jobs,
- to use our imagination and consider alternatives t usual floor mounting of robots, or, not to simply s tate a man with a robot because there may be the b ter ways,
- to start with the simple applications (corollary of Murhpy's law says "If you have 50%-50% chance of s cess, there is a 75% chance of failure".)

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

2. THE ANALYTIC HIERARCHY PROCESS

Industrial processes today seems to consist of many complex nonlinear problems which feed one another. I industrial plant can be described as a complex syste of interacting factor. It is a network of factors wh causes and effects are not easily identified. Nearly of us have been brought up to belive that clear hea logical thinking is our only sure way to face and so complex problems. Our feelings and our judgments mus be subjected to the rigorous test of deductive thin But experience suggests that deductive thinking is s not natural, so we have to be trained, and for a lo 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 |8,9| 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 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 from 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-a 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 of 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 afirmation
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 WELDING WORKING PLACES AND OPERATIONS IN SHIPYARD

Welding operations in shipyards are very important,hard, dangerous and fatiguing jobs. These operations cover aproximately 28-30% of overall operations in shipbuilding industry, and about 38-40% of energy consumption in shipyards |5,7|. For these reasons mechanization or even robotization of these operation have to be one of the vital goals in terms of increasing productivity and effectivies in shipbuilding industry.

Welding operations in Shipbuilding industry "Split" are divided in two main areas:

1. welding operations for ship hull construction (BT),
2. all other welding operations (O).

This global division is made after detailed inspection of all the places and locations in shipbuilding industry "Split" where welding operations take place.

In these main areas we distinguish ten (5+5) main locations, and these locations are as follows:

1. Area BT (ship hull construction):
   - LP – panel line,
   - MP – small assembly line,
   - P – assembly line,
   - N – ship on pedestal,
   - S – special products line.
2. Area O (all other locations):
   - K – crane wheels,
   - AD – autocrane parts,
   - PM – motor and pump supports,
   - PC – pipes an tubes,
   - IT – heat exchangers.

All these locations are carefully inspected and welding operations and methods are systematicaly investigated. The aim of this project is to decide which working locations and operations to chose for the first application of industrial robot for welding. The first step is decomposition of this complex problem as a hierarchy. In the first level of the hierarchy is the overall goal: "The right first application of industrial robot on welding operations in shipyard". In the second level are seven factors of criteria, and in the last, third level are all locations divided in two areas (Fig.1.).

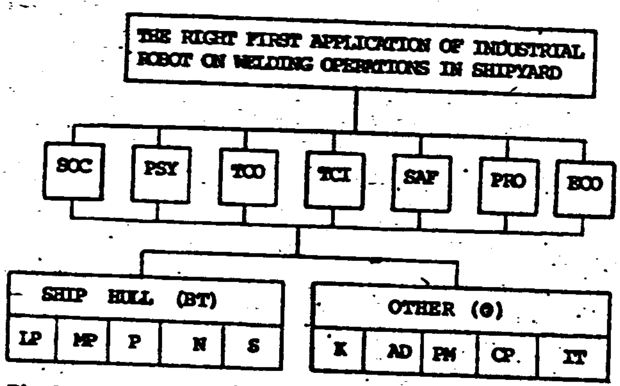


Fig.1. Decomposition of complex problem as a three-level hierarchy

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).

Pairwise comparison matrix for factors of criteria with appropriate priority vector, CI, CR, and λ_{max} is on Table 1. Rang-list of priorities of factors of criteria is on Table 2.

Table 1. Pairwise comparison matrix for factors of criteria

	SOC	PSY	TCO	TCI	SAF	PRO	ECO	PRIORITY VECTOR
SOC	1	1/3	1/3	1/4	1/7	1/6	1/5	0,0286
PSY	3	1	1/2	1/3	1/5	1/4	1/4	0,0495
TCO	3	2	1	1/2	1/4	1/3	1/4	0,0675
TCI	4	3	2	1	1/4	1/3	1/4	0,0931
SAF	7	5	4	4	1	3	4	0,3740
PRO	6	4	3	3	1/3	1	2	0,2060
ECO	5	4	4	4	1/4	1/2	1	0,1810

Pairwise comparison matrices of the main areas (BT and O) for all seven factors of criteria are on Table 3.

Application of the principle of the compostion of priorities gives the vector of global priority of main areas (Table 4.).

Table 2. Rang-list of priorities of factors of criteria

Rang	Factor of criteria	Priority vector
1.	SAF	0,3740
2.	PRO	0,2060
3.	ECO	0,1810
4.	TCI	0,0931
5.	TCO	0,0675
6.	PSY	0,0495
7.	SOC	0,0286

Table 3. Pairwise comparison matrices of the main areas for seven factors of criteria

SOC

	BT	O	V.P.
BT	1	7	0,875
O	1/7	1	0,125

PSY

	BT	O	V.P.
BT	1	5	0,833
O	1/5	1	0,166

TCO

	BT	O	V.P.
BT	1	5	0,833
O	1/5	1	0,166

TCI

	BT	O	V.P.
BT	1	5	0,833
D	1/5	1	0,166

SAF

	BT	O	V.P.
BT	1	7	0,875
O	1/7	1	0,125

PRO

	BT	O	V.P.
BT	1	5	0,833
O	1/5	1	0,166

ECO

	BT	O	V.P.
BT	1	4	0,8
O	1/4	1	0,2

Table 4. Application of the principle of the composition of priorities for deriving the vector of global priority of main areas

	SOC	PSY	TCO	TCI	SAF	PRO	ECO	C.P.V.
	0,0286	0,0495	0,0675	0,0931	0,3740	0,2060	0,1810	
BT	0,875	0,933	0,833	0,833	0,875	0,833	0,8	0,8437
O	0,125	0,166	0,166	0,166	0,125	0,166	0,2	0,1563

Pairwise comparison matrices for five locations of area BT, and for five locations of area O for main four (of seven) factors of criteria are on Tables 5. and 6., respectively. With application of the principle of the composition of priorities on both areas the global area priority vectors are derived (Table 7.).

Table 5. Pairwise comparison matrices for five locations of area BT for main four (of seven) factors of criteria

SAF

	S	N	LP	P	MP	V.P.
S	1	1/2	3	1/3	1	0,135
N	2	1	4	1/2	5	0,302
LP	1/3	1/4	1	1/5	1/3	0,056
P	3	2	5	1	3	0,389
MP	1	1/5	3	1/3	1	0,117

CI = 0,054 CR = 0,048 λ_m = 5,215

PRO

	S	N	LP	P	MP	V.P.
S	1	1/4	1/3	1/5	1/4	0,055
N	4	1	1/2	1/3	1/2	0,137
LP	3	2	1	1/2	1/3	0,165
P	5	3	2	1	2	0,374
MP	4	2	3	1/2	1	0,270

CI = 0,056 CR = 0,052 λ_m = 5,232

ECO

	S	N	LP	P	MP	V.P.
S	1	1/3	1/5	1/6	2	0,075
N	3	1	1/3	1/4	2	0,135
LP	5	3	1	1/2	3	0,285
P	6	4	2	1	4	0,434
MP	1/2	1/2	1/3	1/4	1	0,072

CI = 0,064 CR = 0,057 λ_m = 5,257

TCI

	S	N	LP	P	MP	V.P.
S	1	1/3	1/4	1/5	1/4	0,054
N	3	1	1/2	1/3	1/2	0,121
LP	4	2	1	1/2	1	0,214
P	5	3	2	1	1/3	0,270
MP	4	2	1	3	1	0,341

CI = 0,088 CR = 0,078 λ_m = 5,351

Table 6. Pairwise comparison matrices for five locations of area O for main four (of seven) factors of criteria

PRO

	K	AD	PM	CP	IT	V.P.
A	1	3	5	3	5	0,465
AD	1/3	1	1/2	1/3	2	0,105
PM	1/5	2	1	1/3	1	0,109
CP	1/3	3	3	1	3	0,243
IT	1/5	1/2	1	1/3	1	0,079

CI = 0,064 CR = 0,058 λ_m = 5,258

SAF

	K	AD	PM	PC	IT	V.P.
K	1	1/3	1/5	1/4	1/3	0,056
AD	3	1	1/3	1/2	1	0,135
PM	5	3	1	2	3	0,389
CP	4	2	1/2	1	5	0,302
IT	3	1	1/3	1/5	1	0,117

CI = 0,054 CR = 0,048 λ_m = 5,215

ECO

	K	AD	PM	CP	IT	V.P.
K	1	1/3	1/4	1/4	1/2	0,067
AD	3	1	1/2	1/2	2	0,180
PM	4	2	1	2	3	0,368
CP	4	2	1/2	1	3	0,277
IT	2	1/2	1/3	1/3	1	0,107

CI = 0,024 CR = 0,021 λ_m = 5,095

TCI

	K	AD	PM	CP	IT	V.P.
K	1	1/2	1/5	1/4	1/3	0,061
AD	2	1	1/4	1/3	1/2	0,095
PM	5	4	1	2	3	0,412
CP	4	3	1/2	1	3	0,285
IT	3	2	1/3	1/3	1	0,147

CI = 0,030 CR = 0,027 λ_m = 5,121

Table 7. Deriving the global area priority vectors

BT	SOC	PSY	TCO	TCI	SAF	PRO	ECO	
	0,0286	0,0495	0,0675	0,0931	0,3740	0,2060	0,1810	Global BT area priority vector
S	0,053	0,053	0,044	0,054	0,135	0,055	0,075	0,0875
N	0,142	0,094	0,268	0,121	0,302	0,137	0,135	0,2037
LP	0,156	0,155	0,384	0,214	0,056	0,165	0,285	0,1645
P	0,455	0,432	0,102	0,270	0,389	0,374	0,434	0,3675
MP	0,195	0,266	0,203	0,341	0,117	0,270	0,072	0,1768

O	SOC	PSY	TCO	TCI	SAF	PRO	ECO	
	0,0286	0,0495	0,0675	0,0931	0,374	0,206	0,181	Global O area priority vector
K	0,076	0,111	0,060	0,061	0,056	0,465	0,067	0,1463
AD	0,076	0,111	0,135	0,095	0,135	0,105	0,180	0,1303
PM	0,465	0,202	0,466	0,412	0,389	0,109	0,368	0,3276
CP	0,214	0,507	0,236	0,285	0,302	0,243	0,277	0,2868
IT	0,169	0,069	0,103	0,147	0,117	0,079	0,107	0,1090

Finally taking in account priorities of areas and priorities of locations in areas the global priority vector of all the locations occurs (Table 8.) and rang-list of the priorities is on Table 9. From Table 9. it is obvious that locations from area BT are on the top of priorities, and that location P (assembly line) is absolutely on the first place with "weighting factor" of 0,31. The conslucion is that *location P (assembly line) from area BT (ship hull construction) is the right location for the first application of industrial robot on welding operations in shipyard "Split".*

Table 8. Global priority vector of all the locations

		area priority vector	priority vector of locations in areas	global priority vector
BT	S	0,8437	0,0875	0,0738
	N		0,2037	0,1719
	LP		0,1645	0,1388
	P		0,3675	0,3100
	MP		0,1768	0,1491
O	K	0,1563	0,1463	0,0229
	AD		0,1303	0,0204
	PM		0,3276	0,0512
	CP		0,2866	0,0448
	IT		0,1090	0,0170

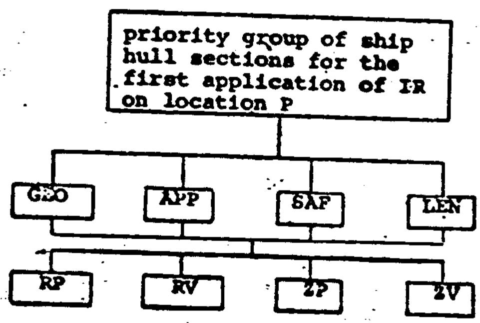
Table 9. Rang-list of the priorities of all the locations

rang	location	area	global priority vector
1.	P	BT	0,3100
2.	N	BT	0,1719
3.	MP	BT	0,1491
4.	LP	BT	0,1388
5.	S	BT	0,0738
6.	PM	O	0,0512
7.	CP	O	0,0448
8.	K	O	0,0229
9.	AD	O	0,0204
10.	IT	O	0,0170

The technological process of welding operations on location P is based on the production of relatively standardised ship hull sections, grouped in four main groups (Fig. 3):

- RP - flat stiffened sections,
- RV - regular space sections,
- ZP - curved stiffened sections,
- ZV - irregular space sections.

If we chose these groups of sections as alternatives, and if the new factors of criteria could be defined, the new three level hierarchy occurs (Fig.2).



The new factors of criteria are:

- GEO - weldment geometry,
- APP - weldments approachability,
- SAF - safety,
- LEN - weldments lenghts.

Pairwise comparison matrix for new factors of criteria with appropriate CI, CR, λ_{max} and priority vector is on Table 10.

Table 10. Pairwise comparison matrix for new factors of criteria

	GEO	APP	SAF	LEN	V.P.
GEO	1	1/4	2	1/3	0,128
APP	4	1	5	2	0,497
SAF	1/2	1/5	1	1/3	0,085
LEN	3	1/2	3	1	0,290

CI = 0,019 CR = 0,021 λ_m = 4,056

Pairwise comparison matrices for four groups of ship sections for four factors of criteria are on Table 11.

Application of the principle of the composition of priorities gives the global priority vectors of standardised sections (Table 12).

Table 11. Pairwise comparison matrices for four groups of ship hull sections for four factors of criteria

GEO

	RP	RV	ZP	ZV	V.P.
RP	1	2	6	9	0,526
RV	1/2	1	5	8	0,344
ZP	1/6	1/5	1	2	0,082
ZV	1/9	1/8	1/2	1	0,047

CI = 0,015 CR = 0,017 λ_m = 4,045

APP

	RP	RV	ZP	ZV	V.P.
RP	1	6	2	9	0,540
RV	1/6	1	1/5	2	0,086
ZP	1/2	5	1	5	0,319
ZV	1/9	1/2	1/5	1	0,055

CI = 0,017 CR = 0,019 λ_m = 4,053

SAF

	RP	RV	ZP	ZV	V.P.
RP	1	5	2	7	0,528
RV	1/5	1	1/4	2	0,105
ZP	1/2	4	1	3	0,294
ZV	1/7	1/2	1/3	1	0,073

CI = 0,028 CR = 0,031 λ_m = 4,085

LEN

	RP	RV	ZP	ZV	V.P.
RP	1	1/2	5	5	0,322
RV	2	1	7	7	0,538
ZP	1/5	1/7	1	1	0,070
ZV	1/5	1/7	1	1	0,070

CI = 0,005 CR = 0,006 λ_m = 4,016

Fig.2. Decomposition of the problem as a three-level hierarchy

Table 12. Application of the principle of the composition of priorities

	GEO 0,128	APP 0,497	SAF 0,085	LEN 0,290	G.P.V.
RP	0,526	0,540	0,528	0,322	0,4740
RV	0,344	0,086	0,105	0,538	0,2517
ZP	0,082	0,319	0,294	0,073	0,2143
ZV	0,047	0,055	0,073	0,070	0,0599

The results derived and presented in Table 12. show that on the priority location P (assembly line) the priority sections for the first application of industrial robot for welding operations are flat stiffened (RP) and regular space (RV) sections.

4. OPTIMAL STRUCTURE AND CONFIGURATION OF INDUSTRIAL WELDING ROBOTS/MANIPULATORS ON THE PRIORITY LOCATION P (ASSEMBLY LINE)

After detailed analysis on the priority location P (assembly line) the next decision occurs: The robotisation of welding operations on this location has to be realized by two different types of robots/manipulators:

1. *Great portal robot* for welding of butt and fillet weldments on floor, vertical and horizontal positions,
2. *universal portable lightweight robot* for fillet overhead weldments , but also for all other types and positions of welding.

4.1. GREAT PORTAL ROBOT

The basic assignment of great portal robot is welding of butt and fillet weldments on floor, vertical and horizontal weldments on location P (assembly line).

Manipulator of such a robot has two main parts, constructively separated but functionally connected in one entireness. These parts are *portal carrier* for two-dimensional X-Y positioning of manipulator arm(s) and *flexible arm(s)* with appropriate welding equipment (Fig.4). The dimensions of the portal carrier are defined with dimensions of standard sections, and typical sections (Fig.5) in Shipbuilding Industry "Split" have basic dimensions as follows:

lenght 10-14 m, extremely 16 m
width 6-12 m, extremely 16 m
height 0,85-2,5 m,

The manipulator arm has to be very flexible, with 5,6 or even 7 degrees of freedom, of robust construction, with all necessary welding MIG/MAG equipment, actuators, sensors, etc. (Fig.6).
The very different dimensions and shapes of ship hull sections and appropriate weldments make special requirements for programming and control of portal robot. The complete exploatation of portal robot possibilities could be achieved with off-line programming and two different approaches to this goal exist:

a) The robot is constituent part of the computer system for ship hull design. All the data about geometry and dimensions of a section are directly communicated to robot automatic control system. This is CAM (computer aided manufacturing) system based on CAD (computer aided design) system for ship hull design.

b) Other approach is, in fact, a compromise between hi-tech robotized production and a relative primitive design stage.

The data about geometry and dimensions of a section are taken from documentation and communicated in the memory of robot automatic control system.

Off-line programming is also used to carry in all the data about welding method, welding velocity, initial and final weldment points, etc.

4.2. UNIVERSAL PORTABLE ROBOT

The primary task of universal portable robot is welding of fillet overhead weldments in space sections but also all other types and positions of welding.
Basic characteristics of such a robot are as follows:

a) *lightweight:* the robot must be compact and portable to weld in confined remote areas,

b) *versatility:* the robot must have multichannel control and the ability to do out-of-position welding,

c) *reliability:* the welding environment requires equipment that is rugged and reliable,

d) *ease of operation:* because of nonrepetitive nature of shipboard and heavy industrial welding,

e) *serviceability:* the robot shuld be of modular construction for ease of repair,

f) *safety:* the robot must be taught in confined areas without danger of harm to the operator.

Manipulator of such a robot has to be of telescopic type, with four main degrees of freedom: translation Z, rotations Θ, ϕ and Ψ and with rotation δ of welding gun gripper. (Fig. 7). Working area is aproximately presented on Fig.8. Schematic presentation of typical working operations of such a robot is presented on Fig.9.
Tehnical characteristics of universal portable lightweight robot are on Table 13.

Table 13. Tehnical characteristics on universal portable lightweight robot

Trajectory "teach-in" velocity	3000	mm/min
Welding velocity	0 - 1000	mm/min
Accuracy	±1	mm
Manipulator mass	30 - 50	kg
Welding gun mass	5	kg
Working area		
Translation	250 + 890	mm
Rotation Θ	± 45°	
Rotation ϕ	± 45°	
Rotation Ψ	± 180°	
Gun gripper rotation δ	± 45°	

Programming and control for such a robot has to be a process with three phases:

I *Programming phase* consists of instructing the robot on the sequence and types of welds to be performed, welding speeds, weaving parameters, voltages and wire speeds (these settings are done on the program panel in the control unit), *II Teaching phase consists* of first moving the welding gun into the initial position and then moving the gun along the weldment trajectory by experienced operator. The weldment trajectory has to be stored in control unit memory. If desired, the program can be checked for accuracy by quickly running through the program and observing the motions of the arm before welding is started.

III Welding phase consists of welding the desired weldment with welding program from the phase I, and by repetition of trajectory teached in phase II.

5. CONCLUDING REMARKS

The conception of industrial robot introduction in shipyards has been developed. The AHP approach has been used as a complex problem-solving framework. The welding operations have been analyzed. The numerical measures of priority of observed locations and operations have been derived. The priority structures and configurations of adequate manipulators for priority location have been determined and their basic preliminary designs have been suggested. 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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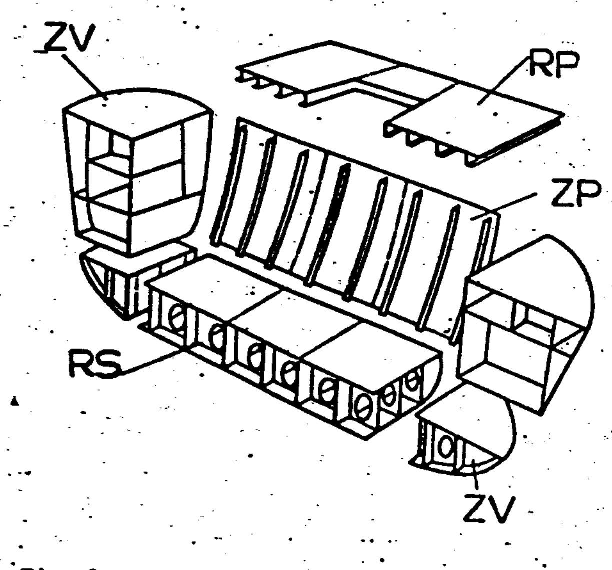

Fig. 3. Standard ship hull sections

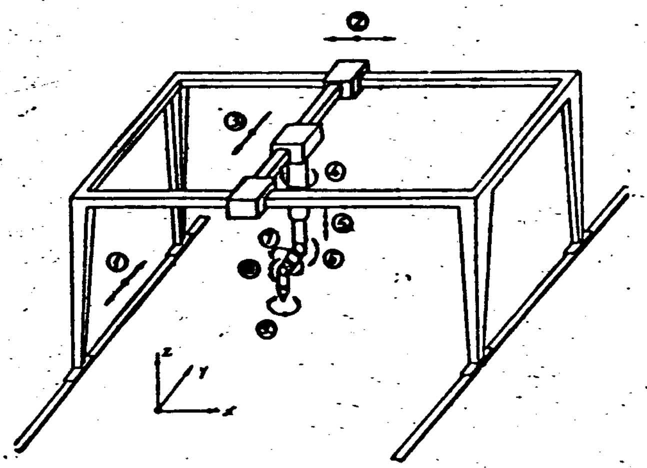

Fig. 4. Great portal robot

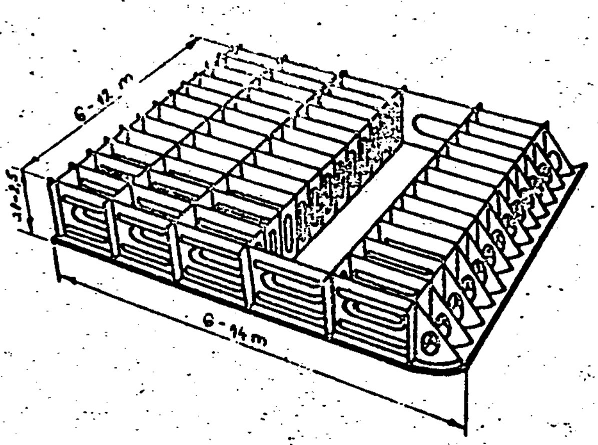

Fig. 5. Typical ship hull section

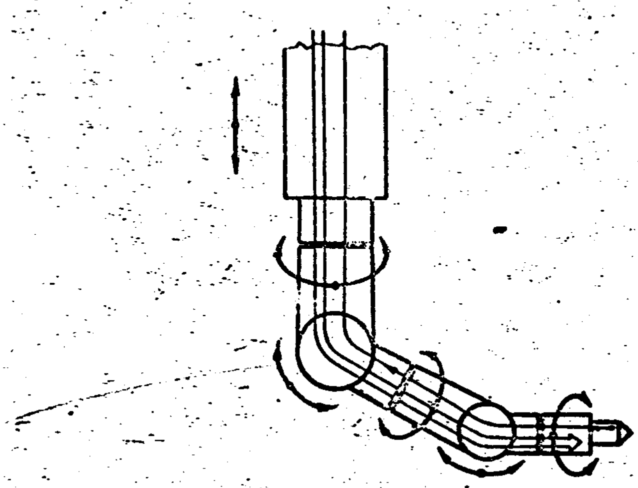

Fig. 6. Flexible portal robot arm

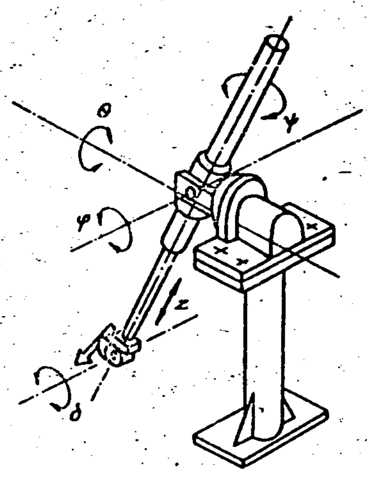

Fig. 7. Universal portable robot

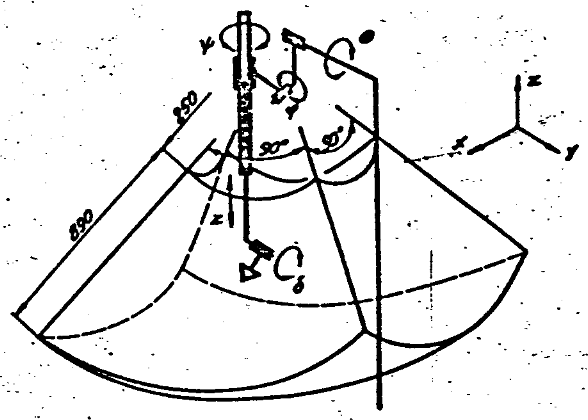

Fig. 8. Working area of universal portable robot

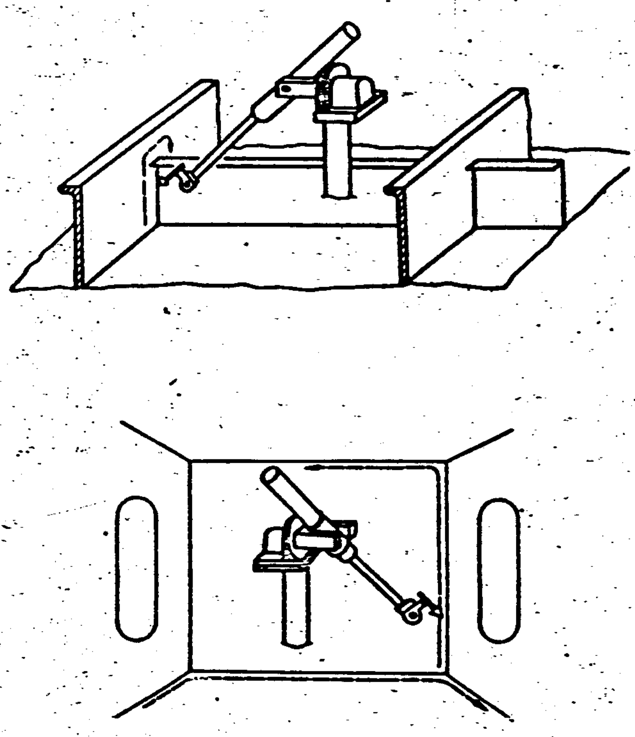

Fig. 9. Schematic presentation of typical working operations of universal portable robot