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Ergonomical Valorization of Working Spaces in Multipurpose Ships

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A B S T R A C T

In this work it is shown how anthropological data are among the most needed factors in ergonomical valorization of crew working spaces. Ship's working or living environment involves many unique human factors, which should be specially considered in our case as limitation of crew space. In this work we have chosen ships of different years of construction to prove this tendency. As a micro study, the work posture analysis using the pulling force experiment is performed in order to determine lumbar moment, intra -abdominal pressure as a measure of evaluating and comparing different crew work positions. As a macro-study, the »crew work posture analysis« was carried out by the use of the data collected from real cases. The most probable work postures in different spaces of a ship are classified and after some corrections of the work place the profile and its grade were determined. The »statistical analysis for real ship's spaces« is also performed, as well as another macro study, in order to show some real designed ship spaces from the point of view of the allocated volume.

Key words: *designing work-living spaces, human factor*

Introduction

Success of technical or industrial systems is generally measured in terms of productivity or output. Effective human performance is a key factor in producing a desired output in a factory, laboratory, construction industry, or in a ship as a complex system.

Past experience has shown, however, that many industrial systems are conceptualized around machinery, materials, and architectural features, with too little thought given to what workers should be doing, how they should be doing it, and what they should be doing it. As a result, these systems tend to be designed more to accommodate the machines and materials than to make sure that workers can contribute maximally to the eventual industrial/system output[1].

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Fortunately, this bias toward the machine rather than the worker in the industrial system is changing through the efforts of ergonomics or the human factors approach to the design of a work system.

Statistical analysis of real ship's spaces

Ship's operational environment creates numerous unique human factor problems that should be addressed early in the conceptual development of any sea borne vessel. These principal factors to consider are the following:

a) *Ship motion (e.g. pitch, roll, heave, etc.)* These motions impact the personnel not only in terms of potential sickness but also in terms of interference and general safety (i.e. loss onboard).

b) *Equipment noise and vibration* Because of the necessity to conserve space and minimize vessel size, personnel and equipment must necessarily be housed in close proximity. Adequate noise and vibration control is required in order to maintain crew performance at acceptable levels. Control must be exercised not only in working spaces but also in living spaces.

c) *Atmospheric control* Vessels present unusual atmospheric control requirements in order to maintain the crew in a healthy and efficient state. The idea that unfavorable environments are just part of the job is no longer valid within the context of the more sophisticated and demanding systems of today, in which human failure can no longer be tolerated. Air conditioning for crew living spaces is as important as it is for electronic equipment if the total human-machine system effectiveness is to be maintained.

In such an environment, lack of space is often the result of a failure to appreciate the way in which space impacts the crew performance. The traditional ship architecture tends to follow outmoded trends toward designing crew spaces according to »minimums«, as opposed to creating spaces that will maximize the crew performance effectiveness. The principal space-related features of vessels that make a considerable difference in the crew performance effectiveness are the following:

1. *Head clearance*. Traditionally, low overheads are created because between deck dimensions are based on minimum head clearances. In many cases it is forgotten that pipes and ducts, which will consume part of the space, will be installed. The worst problems are created when multiple berthing is imposed and the berth has so little vertical separation that crewmembers cannot sit up in their bed. This is more than a matter of convenience, as lack of head clearance often leads to unnecessary head injuries and/or to inefficiencies such as slowing the movement of the personnel through passageways.

2. *Cramped living and working conditions*. Lack of adequate planning in the initial conceptual phase creates spaces that interfere with job efficiency because of restrictions on mobility. More prevalent, however, is the restriction imposed on the general habitability of the crew living quarters where there is insufficient space for storing personnel belongings, relaxing, or performing personal hygiene tasks, such as toilet, showering, and dressing.

3. *Passageway clearance*. Not only it is important to create passageways and hatches that are large enough for crew transfer, but it is also mandatory that such passageway clearance accommodates passage of the crew members and the equipment they may have to transfer from one part of the ship to another.

4. *Space organization*. Organization of ship space requires obvious compromises. However, human requirements for basic

living and work convenience are the key to the effective crew performance and eventual mission success. The crew-occupied space must be compatible not only with environmental needs (e.g. isolation from excess ship motion, vibration, and noise) but also with the typical personnel traffic patterns as these relate to crew fatigue and time lost en route from one space to another. Traffic patterns should be thoroughly analyzed from both nominal and emergency standpoint.

The amount of space allowed for each person aboard ship should be based not on rank but on need. Everybody requires approximately the same amount of space for sleeping, storing clothing, dressing, showering, etc. Where needs differ in terms of space requirements, the decision should be based on special tasks that various members of the crew have to perform. For example, top-level officers require private conference space, middle -management officers require special space for bookwork, and others require special space for record keeping.

Everybody aboard ship has the same basic need to have adequate space to store their belongings in a secure and convenient manner. There can be no defensible rationale for forcing an enlisted person to stuff garments and personal articles into a bag or under a mattress.

Methods

In this work, the crew works posture, as one of the critical human factor considerations will be reviewed in different ship spaces[2]. Whether crews are standing or seated at a workbench or machine, their working posture is extremely important. That is, if the hardware forces crew to remain in an awkward position for a long time, they obviously will become fatigued and will be more apt to make mistakes or incur some type of physical disability over a period of time[3,4].

In order to show the real direction of designing ship space from the viewpoint of the value of the allocated volume, we have collected the required data from existing Iranian ships. In this approach, a multi-purpose type vessel is chosen because of her broad range of usage. There are many difficulties in accessing the ships' drawings and the required data and information, because many authorities consider these confidential[7].

Three different multi-purpose vessels, belonging to IRISL (Islamic Republic of Iran Shipping Line) with the following constraints were available:

1. The only available drawings of each vessel were the general arrangement plan and the capacity plan of the tanks.
2. The required details, such as Cb (block coefficient) were not available. To determine the volumes of some parts of the hull, an approximate Cb for those parts were assumed, or by using the »Simpson's rule« the volumes were calculated.
3. These vessels were made in different years of construction: 1977, 1922 and 1998.
4. Vessels of different sizes and capacities were chosen.

The further steps of the mentioned statistical analysis are:

1. Calculating the volumes of all individual spaces of every ship (hull and superstructure), without considering internal structures, insulation, etc., so that they are molded volumes.
2. Splitting the calculated spaces into three general groups: payload spaces, machinery and apparatus spaces, crew working and living spaces.
3. Dividing the crew working places as well as the living places, according to the purpose of every individual space.
4. All mentioned spaces were determined as a percentage of the whole volume of the respective vessel.

Workplace analysis regarding crew work postures

There are different tasks done onboard ship with different body postures. Therefore an ergonomic study of crew work postures is needed. Nearly in all cases the number of crew per each group of task is fixed. This is because the various groups require different training, knowledge and experience.

In this work, the crew work postures' study was carried out by means of observation, interview, and by using a prepared questionnaire, by the support of IRIS (Iranian Shipping Line).

In this approach more than 50 copies of the mentioned questionnaire were filled up through observing and interviewing different ranks of ship crew: captains, chief engineers, chief officers, cadets, cook, start, etc. In some cases the incorrect information were deleted and incomplete ones were modified (Table 1a).

Analyzing method

The most probable work postures in ship's different spaces were classified in 13 different postures. In this regard the method of specified work postures with associate effort points is used[6]. The points were expressed as scores ranging from 1 to 5 (Table 1b).

In some cases the scores were corrected according to the movement and/or stair existence in each workplace in each workplace (Table 2). The frequency per hour of the works was not considered, because the work activities in the ship is not like a production line, e.g. car manufacturing, which has repetition of the same work all time.

Then the workplace profile was expressed as grades ranging from 1 to 4. This was done by help of a special table where the efforts of the workers are graduated with adequate scores (Table 3).

In Table 4 is presented the percentage, for all three analyzed vessels, of total volume for different spaces, e.g. pay load space, machinery and apparatus spaces, crew working and living spaces.

It should be mentioned that, in the above method, the specified work postures in ship's different spaces and the needed correction should usually be based on past experience, either of the individual doing the analysis or someone familiar with similar systems already in use.

TABLE 1A

THE PREPARED QUESTIONNAIRE (WHERE A–M ARE SPECIFIED WORK POSTURES (SEE TABLE 1B))

Place	A	B	C	D	E	F	G	H	I	J	K	L	M	Remarks
1. Bridge and radio room														
2. Deck														
3. Control room														
4. E.R. & maintenance works														
5. Work shop														
6. Galley														
7. Mess														
8. Cargo hold														
9. Store														
10. Others														

TABLE 1B
SPECIFIED WORK POSTURES, AND SPECIFIED POINTS FOR WORK POSTURES

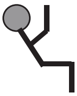
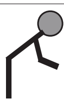
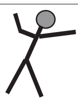
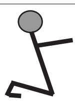
		Work posture	P (point)
A		Sitting, vertical trunk	1
B		Sitting, trunk bent forwards	2.5
C		Sitting, trunk bent sideways	2.5
D		Sitting, trunk bent backwards	5
E		Standing, vertical trunk	2
F		Standing, trunk bent forwards (20°)	2.5
G		Standing, trunk bent forwards (40°)	3
h		Standing, trunk bent forwards (60°)	5
I		Standing, trunk bent sideways	4
J		Standing, trunk bent backwards	5
K		Standing, legs bent	4.5
L		Kneeling	4.5
M		Squatting	5

TABLE 2
CORRECTION TABLE

Stairs (easy) 0.3–0.5 m	Stairs (awkward) > 0.5 m	Correction	Movement (if P > 4) speed
3–5 time/min	1 time/min	+ 0.5	< 2 m/min
> 5 time/min	> 2 time/min	+ 1	> 2 m/min

TABLE 3
WORKPLACE PROFILE

Score	Profile of workplace	Workplace grade
1–2	Good (good situation)	1
2–3	Acceptable (optimize if possible)	2
3–4	Hard (improvement in time desirable)	3
4–5	Very hard (immediate improvement needed)	4

TABLE 4
PERCENTAGE OF TOTAL VOLUME FOR DIFFERENT SPACES

Space (m^3)	1 vessel (1977) complement 30	2 vessel (1992) complement 32	3 vessel (1998) complement 36
Pay load space[1]	62	62	66
Machinery and apparatus spaces and all tanks[2]	23	30	27
Crew working and living spaces[3]	15	8	7

[1] including cargo holds;

[2] including engine room and funnel, pipe tunnel and duck keel, tanks and void, stores, auxiliary. machinery and out-fitting, etc.;

[3] including living room, office, machinery control room, shop, mess-room, galley, wheelhouse, etc.

Results

Analysis of real ships' spaces

The results of the statistical analysis of some real ships' spaces by the above method have been collected, divided into different groups and then compared. From Table 4, it is clear that as the portion of »pay-load space« of total volume is increased the portion of »crew working and living spaces« is decreased. The percentage of total volume per person for living and working spaces are given i Table 5.

Table 6. shows rapid reduction in size of »crew working and living spaces« per person.

The decrease of the portion of »personal and public spaces« per person is shown in Table 7.

Reductions in different working spaces per person are somewhat shown in Table 7 and Figure 4.

In Table 8 the decrease of the average volume of living space per person is shown.

Reduction in the volume of working spaces per person is somewhat shown in Table 6 and Table 9 shows rapid reduction in size of »crew working and living spaces« per person.

TABLE 5
PERCENTAGE OF TOTAL VOLUME PER PERSON FOR LIVING AND WORKING SPACES

Space (m^3)	1 vessel (1977) complement 30	2 vessel (1992) complement 32	3 vessel (1998) complement 36
Living and related spaces[1]	12/30 = 40 × 10^{-2}	6/30 = 18.7 × 10^{-2}	5/30 = 13.9 × 10^{-2}
Working and related spaces[2]	3/30 = 10 × 10^{-2}	2/30 = 6.2 × 10^{-2}	2/30 = 5.6 × 10^{-2}

[1] including living room, mess-room and pantry, galley, hospital, praying-room, passage and ladder, gymnasium, rec. room, lounge, W.C., changing room, etc.;

[2] including shops, machinery control room, wheelhouse, navigation and common, offices, fire control room, CO_2 room, etc.

TABLE 6
PERCENTAGE OF TOTAL VOLUME FOR LIVING SPACES PER PERSON

Living space (m^3)	1 vessel (1977) complement 30	2 vessel (1992) complement 32	3 vessel (1998) complement 36
Personal[1]	6.2/30=20.6 × 10^{-2}	2.8/30=8.7.7 × 10^{-2}	2.5/30=6.9 × 10^{-2}
Public[2]	35.930=19.6 × 10^{-2}	3.4=10.6 × 10^{-2}	2.5/30=6.9 × 10^{-2}

[1] including living room;

[2] including mess-room and pantry, galley, hospital, praying room, passage and ladder, gymnasium, etc.

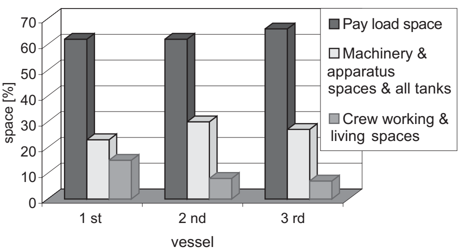


Fig. 1. Percentages of total volume for different spaces.

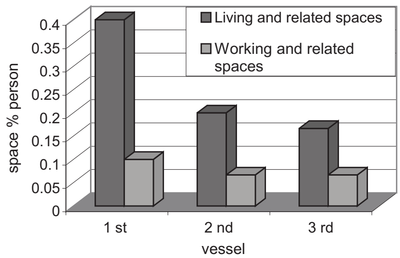


Fig. 2. Percentage of total volume per person for living and working spaces.

TABLE 7
PERCENTAGE OF TOTAL VOLUME FOR WORKING SPACES PER PERSON

Working space (m^3)	1 vessel (1977) complement 30	2 vessel (1992) complement 32	3 vessel (1998) complement 36
Ship/machinery control spaces[1]	1.24/30=4.1 × 10^{-2}	0.67/32=2.1 × 10^{-2}	1.2/36=3.3 × 10^{-2}
Managing and maintenance spaces[2]	1.92=6.4 × 10^{-2}	1.31/32=4.1 × 10^{-2}	1.16/36=3.2 × 10^{-2}

[1] including machinery control room, wheelhouse, navigation and common, fire control room, CO_2 room, etc.;

[2] including shops and offices.

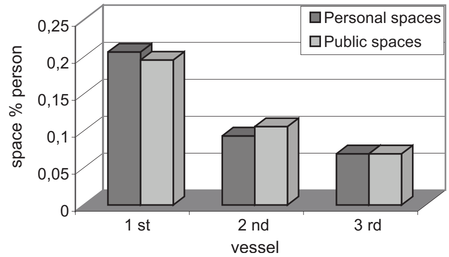


Fig. 3. Percentage of total volume for living spaces per person.

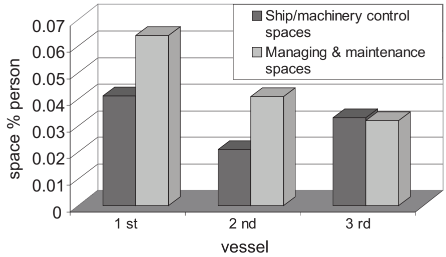


Fig. 4. Percentage of total volume for working spaces per person.

TABLE 8
LIVING SPACES VOLUME PER PERSON (m^3)

Living Spaces (m^3)	1 vessel (1977) complement 30	2 vessel (1992) complement 32	3 vessel (1998) complement 36
Personal[1]	2390/30 = 79.6	1510/32 = 47.1	1191/36 = 33
Public[2]	2275/30 = 75.8	1803/32 = 56.3	1204/36 = 33.4

[1] including living room;

[2] including mess-room and pantry, galley, hospital, praying room, passage and ladder, gymnasium, rec. room, lounge, W.C., changing room, etc.

TABLE 9
WORKING SPACES VOLUME PER PERSON (m^3)

Working Space (m^3)	1 vessel (1977) complement 30	2 vessel (1992) complement 32	3 vessel (1998) complement 36
Ship/machinery control spaces[1]	480/30=16	356/32=11.1	572/36=15.8
Managing and maintenance spaces[2]	741/30=24.7	699/32=21.8	551/36=15.3

[1] including machinery control room, wheelhouse, navigation and common, fire control room, CO_2 room, etc.;

[2] including shops and offices.

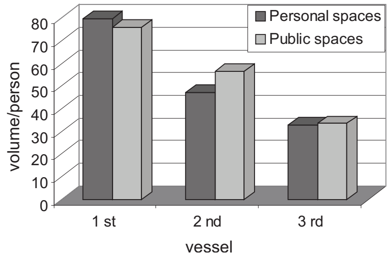


Fig. 5 Living spaces volume per person (m^3).

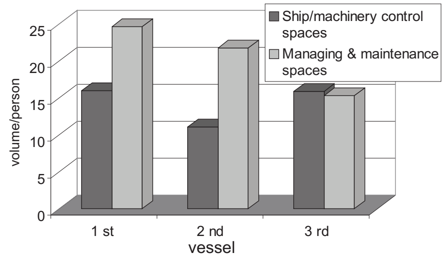


Fig. 6. Working space volume per person (m^3).

Ergonomically study of workplaces, regarding crew work postures

Through direct observation, interview, and distributing the prepared questionnaire (Table 1a) among crew of different ranks, work postures that might be more probable existing in each workplace, were distinguished.

Work postures in any questionnaire were scored using the Table 1b.

The correction was done for any individual work posture using the correction table (Table 3). Then the average score for each of ten places in each questionnaire were determined. One of the samples is shown in Table 10.

In the next step, all the scores of each individual place were averaged. The final scores of all places are shown in Table 11.

Using the method of specified work postures with associated effort points, (Tables 10 and 11), the grade of workplaces and also the workplace profile were defined. Finally, in Table 12 is given grade and workplace profile.

In our research the hardest place from the standpoint of working space, is engine room (E.R.), which immediate improvement is needed to bring it in a better situation.

Here, we review some usual works in E.R. and propose some solutions, according to Iranian anthropometric measures.

There are always many work postures for some activities at the same place, e.g. working on upper parts of engine, which is done in a difficult posture, e.g. standing while trunk bent, somehow, backwards. In such a cases there are some solutions in order to combat and modify the work posture and do the task with less trouble for back and knee (here, numbers are for 95% for Iranian ship crew)[7].

To modify squatting and/or kneeling postures when working on machinery, e.g. pumps, engines, filters, etc., when replacing/repairing them, a suitable pit having cover, in double bottom and/or bilge area, is designed adjacent to these items, where it is possible considering water-tightness and/or non-water-tightness of that area (Figure 7).

Also, it is possible to install the pumps, compressors, etc. of smaller weights, on a platform having proper height on bulkhead (Figure 8).

To modify standing posture while trunk bent, somehow, backwards, when working on upper parts of main engine, generators, etc. permanent and/or temporary

TABLE 10
A FILLED QUESTIONNAIRE, AS A SAMPLE

Place	A	B	C	D	E	F	G	H	I	J	K	L	M	Remarks
1. Bridge and radio room	*					*								
2. Deck					*	*		*			*		*	
3. Control room	*	*	*		*		*							
4. E.R. & maintenance works					*	*	*	*		*	*	*	*	
5. Work shop	*	*			*	*	*	*			*		*	
6. Galley	*	*			*	*								
7. Mess	*				*	*								
8. Cargo hold					*	*					*		*	
9. Store	*				*	*					*			
10. Others	*													

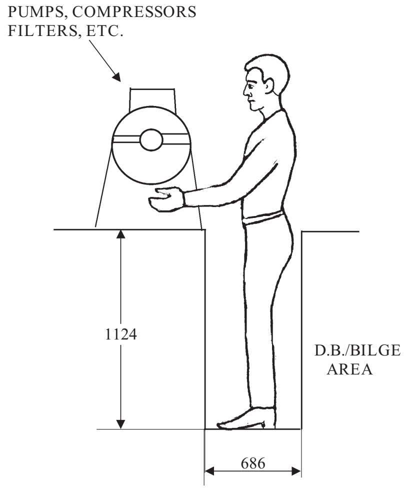


Fig. 7. Proposed solution to modify postures when working on small machineries.

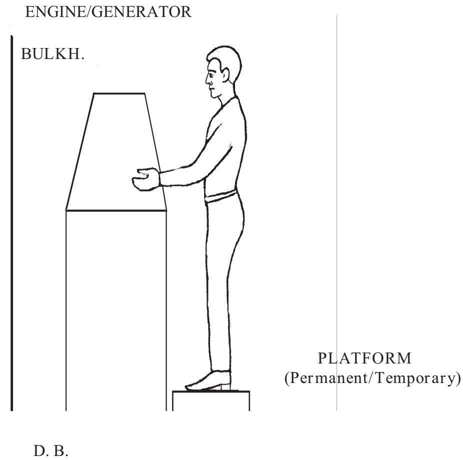


Fig. 9. Proposed solution to modify postures when working on machinery and generators.

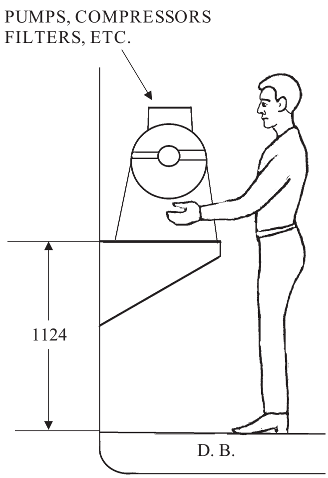


Fig. 8. Proposed installation height for small machineries.

rising platforms or the like is designed (Figure 9).

Discussion and Conclusions

By our method of profiling workplaces, the rate of paying attention to the different workplaces will be determined. Then, they will be optimized if possible, improved in time desirable and/or improved immediately. And also, the above grading and profiling method could be a sample method of reviewing and analyzing other workplaces in different fields, in viewpoint of work posture. Such a kind proposals leads to higher health, which causes higher efficiency due to less strain and fatigue, less accident, less mistake, and less rest. Lower cost of remedy, which is caused by sickness and body efficiency. Longer period of age for experienced crew being onboard, which is because of the health and better work postures. A proper means for determining the size of hardship of any individual workplace, which could affect on the wages of the crew.

In our research the hardest place is engine room (E.R.), which immediate improvement is needed to bring it in a better situation. Here, we review some usual works in E.R. and propose some solutions, according to Iranian anthropometric measures.

TABLE 11
FINAL SCORES OF DIFFERENT PLACES

Place	A	B	C	D	E	F	G	H	I	J	K	L	M	Final score
1. Bridge and radio room														1.9
2. Deck														3.7
3. Control room														2.5
4. E.R. & maintenance works														4.1
5. Work shop														3.2
6. Galley														2.9
7. Mess														2.4
8. Cargo hold														3.6
9. Store														2.8
10. Others														1.3

TABLE 12
WORKPLACE GRADE AND WORKPLACE PROFILE

Place	Final score	Work place grade	Work place profile
1. Bridge and radio room	1.9	1	Good
2. Deck	3.7	3	Hard
3. Control room	2.5	2	Acceptable
4. E.R. & maintenance works	4.1	4	Very hard
5. Work shop	3.2	3	Hard
6. Galley	2.9	2	Acceptable
7. Mess	2.4	2	Acceptable
8. Cargo hold	3.6	3	Hard
9. Store	2.8	2	Acceptable
10. Others	1.3	1	Good

There are always many work postures for some activities at the same place, e.g. working on upper parts of engine, which is done in a difficult posture, e.g. standing while trunk bent, somehow, backwards. In such a cases there are some solutions in order to combat and modify the work posture and do the task with less trouble for back and knee (here, numbers are for 95% for Iranian ship crew).

Because of economic reasons it is natural to design and build vessels with higher capacities, which need to have more crew onboard. Although it is natural to reduce crew to some extents due to automation, crew training, etc. and although within certain broad limits the same size crew is required regardless of ship size, but as the results of the above investigations have shown, there is a reduction in the volumes of living and working spaces in lieu of each person.

In other words, regarding the capacity as well as the year in which the ships were built, there are possible conclusions: Along with the increase in volume of payload spaces, so that the vessels are bigger and more crew is needed, the volumes of living and working spaces in lieu of each person are tend to be reduced. Along with designing/building new ships, considering the construction year, the above conclusion could also be concluded.

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ERGONOMSKA VALORIZACIJA RADNIH MJESTA U VIŠENAMJENSKIM BRODOVIMA

SAŽETAK

U radu je prikazano kako su antropometrijski podaci među najpotrebnijim čimbenicima u ergonomskoj valorizaciji radnih mjesta posade broda. Radni okoliš na brodu, kao i onaj koji se koristi u slobodno vrijeme, uključuje više jedinstvenih ljudskih čimbenika koje treba posebno razmotriti u našem slučaju, kao ograničenje prostora za posadu broda. U ovom radu izabrali smo brodove različitih godišta proizvodnje kako bi dokazali ovu tendenciju. Kao mikrostudija, analiziran je stav tijela prilikom rada te je napravljen eksperiment korištenjem vučne sile u cilju određivanja pokreta u slabinskom području, intraabdominalnog pritiska kao mjere procjene te uz usporedbu različitih stavova tijela članova posade tijekom rada. Kao mikrostudija, provedena je »analiza stava tijela brodske posade tijekom rada« korištenjem podataka prikupljenih na stvarnim slučajevima. Najvjerojatnije pozicije tijela u radu u različitim prostorima broda klasificirane su i nakon nekih korekcija radnog mjesta određen je profil i stupanj. Također je provedena statistička analiza stvarnog prostora broda, kao i druga makrostudija, kako bi se pokazalo neke u stvarnosti dizajnirane prostore broda sa stanovišta alociranog volumena.