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RISK-BASED ANALYSIS OF OPERATIONAL DESIGN RESTRICTIONS AND MAIN DESIGN CHARACTERISTICS OF SUBSEA CONSTRUCTION VESSELS

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Abstract. *An analysis of main dimensions and weight loads of existing subsea construction vessels has been carried out. Initial design stage characteristic curves of determination of main characteristics of new generation with taking into account risk analysis and operating experience are obtained.*

Keywords: *vessel; subsea operations; main dimensions; weight load; risk; design; operation.*

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РИЗИК-ОРІЄНТОВАНИЙ АНАЛІЗ ЕКСПЛУАТАЦІЙНИХ ПРОЄКТНИХ ОБМЕЖЕНЬ ТА ОСНОВНИХ ПРОЄКТНИХ ХАРАКТЕРИСТИК СУДЕН ДЛЯ ПІДВОДНОГО БУДІВНИЦТВА

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Виконано аналіз головних розмірень та вагових навантажень існуючих суден забезпечення підводно-технічних робіт.

Отримано залежності визначення основних характеристик досліджуваного типу суден нового покоління на початковому етапі проектування з урахуванням аналізу ризику та досвіду експлуатації.

Ключові слова: *судно; підводно-технічні роботи; основні розміреня; вагове навантаження; ризик; проектування; експлуатація.*

The publication considers the conditions for the influence on the speed of the vessel of the characteristic curves of changes in the main dimensions, coefficients of completeness and changes in the weight load, taking into account the risks arising during the operation of subsea construction vessel.

Many authors have considered the effects of changes in the main dimensions and coefficients of completeness on the speed of the vessel [1, 3, 6-8], while in all cases the considered factors were associated with the seaworthiness of the vessel.

Studies related to the change in weight load [2] were considered mainly for ships of the transport and passenger fleet. Considering the above tasks of the study, the risks developed by the authors and regulated by International standards [4, 5] are taken into account and applied for the case under consideration, for cases arising during the operation of subsea construction vessel.

With the development of ships of the technical and technological fleet, there is a need to link the tasks of changing the main dimensions and weight load with the technological complexes and hardware installed on the ship, taking into account the possible risks of operating ships of the class in question.

Formulation of the problem. In this paper, it is planned to investigate the relationship between the conditions for changing the main dimensions and the nature of changes in the weight load of the subsea construction vessel with the parameters of the complexes and hardware used, taking into account the analysis of risks arising from the operation of the types of vessels under study.

Condition of influence on the vessel speedof the main dimensionand weight loading. When designing ships that perform underwater technical work, the dimensions and parameters of technological equipment, hardware and diving systems affect the formation of the main dimensions, which, in turn, obviously affects the speed of the designed vessel.

From the main dimension of support vessels of subsea operation, on influence on vessel speed width and draft of the vessel which are appointed proceeding from a design assignment is accepted by the most critical or are defined by a settlement way at early design stages, using data of vessels of prototypes or statistical data of the same vessels, taking into account restrictions on processing equipment. Other dimensions, such as length, board height, etc., at settlement definition of the main dimension, can be chosen on ratios of L/B, B/T, B/H, etc. Considering the told conditions, influence of the main dimension of the designed vessel on speed, taking into account the identified risks, is expressed by function (1)

$$v = Rf(D, L, B, T). \quad (1)$$

Here v – vessel speed;
L, B, T – main dimension the designing vessel;
R – the designing vessel identified risk;
D – displacement.

Formations of the main dimension of the designed vessel, taking into account design restrictions and interrelation of the factors forming the main dimension are reflected in the block diagram in figure 1.

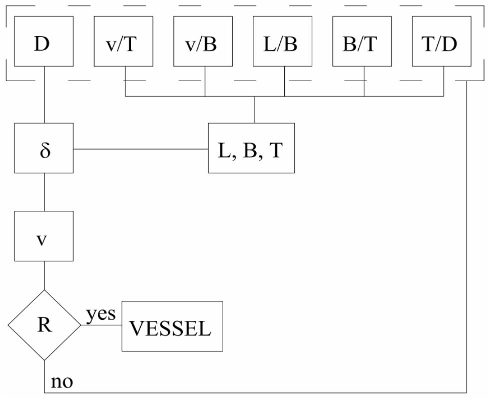

Fig. 1. The block coefficient influence main dimension on the vessel speed

Figures 2 and 3 show the graphs of the ratios of speed - draft and width of ships. When forming the schedules, statistical data were used for 40 subsea construction vessels, for 20 diving vessels, for 24 hardware carrier vessels and for 18 manned underwater vehicle ROV/AUV carrier vessels.

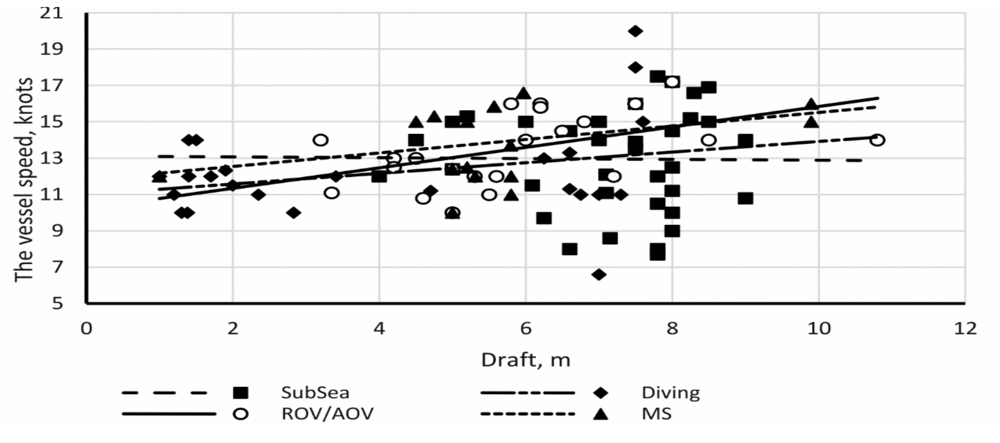

Fig. 2. Draft and speed ration of the vessel

Apparently from ratios, dynamics of the schedule in figure 3., differs, at vessels of MS carriers that is depend with rather small width of a hull of MS support vessel. At the same time on support vessels of subsea operation of the identically of the schedule it is similar to figure 2 ratios.

In relation to the considered task, with the conditions influencing the speed of the designed vessel as it was told above, are allocated, sizes of width and draft of the vessel. Considering the statistical data provided on figure 2, influence of draft on speed of the designed vessel, is reflected in expression (2)

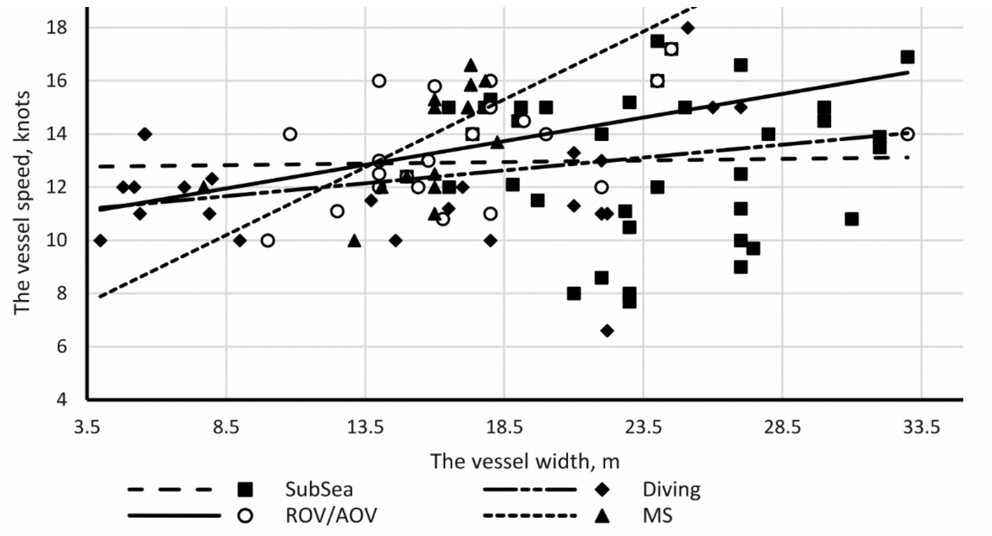

Fig. 3. Width and speed rating of the vessel

$$v = b * T - v / T \quad (2)$$

Here v – vessel speed;

T – draft from change the vessel speed;

b – correlation coefficient the considering regularity of the considered ratios determined by formula (4);

v/T – ratios of speed and draft of the vessel, determined by formula (3).

$$v / T = \sum_{i=1}^{n} \overline{v} - b * \sum_{i=1}^{n} T \quad (3)$$

$$b = \frac{\sum_{i=1}^{n}(T - \overline{T}_i)(v - v_i)}{\sqrt{\sum_{i=1}^{n}(T - \overline{T}_i)^2 \sum_{i=1}^{n}(v - \overline{v}_i)^2}} \quad (4)$$

Based on the statistical data provided on figure 3. vessel speed is defined. A conclusion of value of vessel speed depending on width of the case is reflected expression (5).

$$v = b * B - v / B \tag{5}$$

Here B – width, depend from measurement speed the vessel;

b – correlation coefficient the considering regularity of the considered ratios determined by formula (7);

v / B – ratios of speed and the vessel width, determined by formula (6).

$$v / B = \sum_{i=1}^{n} v - b * \sum_{i=1}^{n} B \tag{6}$$

$$b = \frac{\sum_{i=1}^{n} (B - \overline{B}_i)(v - \overline{v}_i)}{\sqrt{\sum_{i=1}^{n} (B - \overline{B}_i)^2 \sum_{i=1}^{n} (v - \overline{v}_i)^2}} \tag{7}$$

Risk analysis in operation of supply vessels. Use of a large number of expensive processing equipment, the ROV/AUV equipment and diving complexes to focusing in one vessel raises degree of risk of operation of the designing vessel. For anticipation of emergencies, the analysis of a part of the risks arising during the perform of the subsea vessel operation is made below. Investigating the risks connected with design of support vessels of subsea and technical works identification, the description, sources, risk analysis and the system of actions anticipatory risks are considered.

The risk identification. When forming the idea of the perspective vessel, among a large amount of risks, with the most priority when forming design restrictions of the designed vessel, are allocated:

- the risks arising when forming weight loading at a stage of early (research) design of the vessel;
- the risks arising when forming the main dimension of the perspective vessel at a stage of early (research) design;
- the risks arising when calculating speed of the designed vessel.

Description of risks. The risks arising at a stage of early design, in particular formation of weight loading definition of the main dimension and calculation of vessel speed are described as:

- Errors of formation of weight according to sections of weight loading;
- Incorrect choice of rations of the main dimensions;
- Errors when calculate vessel speed.

Sources of risk. *The insufficient mass of loading of masses according to sections concerning the displacement of the designed vessel. At a stage of initial design, when* *forecasting loading of masses, on formation finally of the displacement of the designed vessel, a large number of factors influences.*

It is possible to carry to similar factors, an error of the choice of sections of loading of masses in the top and lower limits, unjustified forecasts of mass of the equipment, a mistake when calculating and choosing coefficients of completeness and the main dimension.

The incorrect choice of ratios of the main dimensions of the perspective vessel, at a stage of initial design, can arise at the incorrect choice of the sizes in the maximum and minimum limits of ratios of the main dimensions.

As communication with the previous risk, influence on vessel speed among big quantity of factors, in relation to the considered task it is possible to allocate errors when choosing the main dimension and coefficients of completeness.

Risk analysis. For formation of actions for anticipation of the identified risks at a stage of initial design, is lower in table 1., the analysis of the identified risks for a stage of initial design is provided.

Table 1

Risks in the formation of the ship's weight load	Risks in the formation of the main dimensions of the vessel	Risks arising from the calculation of vessel speed
Errors of sections of loading of mass of the designed vessel, as a result can bring: 1. To weighting of the vessel that in turn will effect on: – Increase in displacement; – Increase the fact draft; – Loss speed (from ratios v/T); – To reduction of loading capacity, possibilities of use of processing equipment are as a result narrowed. 2. To simplification of the vessel that in turn will effect on: – Decrease the displacement; – Decline in stability of the vessel; – Increase in value of the section of loading of masses "ballast"; – Problems from use the technology equipment.	The incorrect choice of ratios of the main dimension and as a result formation of the main dimension on the chosen ratios, can bring to: – Receiving is less than predicted speed; – Receiving is more than predicted displacement; – Decline stability. Told above in all cases can give to problems in operation of processing equipment.	Error when calculating vessel speed can bring to: – Incorrect select the ratios T/v; – Incorrect select ratios B/v; – Incorrect select ratios L/B.

Action system anticipatory risks

1. It is necessary for anticipation of the risks connected with formation of weight loading:

– At initial design stages to make the reasonable choice of the predicted values of sections of weight loading being based on the data of the vessel of a prototype or statistical data on the same vessels;

– At initial design stage to predict, necessary value of a stock displacement;

– All stage creation of the vessel, from development of the idea before delivery of the vessel in operation to make strict control of formation of sections of weight loading.

2. It is necessary for anticipation of the risks connected with formation of the main dimension of the vessel:

– At initial design stages to show consideration for the calculations of the sizes important for the perspective vessel;

– To show consideration for the choice of a prototype or statistical these same vessels;

– When choosing the main dimension of the vessel to consider the most adverse operating conditions of processing equipment, complexes and hardware.

3. It is necessary for anticipation of the risks connected with calculation of speed:

– At all design stages and constructions of the vessel to watch closely change of the conditions considered during the calculating of speed, a research in the model testing basin and at CFD modeling of the case;

– At a design stage to connect theoretical calculations of seaworthy qualities of the vessel with calculation of vessel speed.

As a result, the analysis of the identified risks considered above shows that all considered risks are interconnected. Anticipation of the identified risks, it has to be made at all design stages and construction of the perspective vessel.

Research of reqularities of change of weight loading. Having statistical values of weight loading of the vessels which are in operation it is possible, at a stage of initial design, with rather high share of probability to determine the exact predicted values of loading of masses by articles. Below, schedules of ratios of displacement empty and separate articles of loading of mass of vessels are reflected in figure 4. When forming schedules statistical data about 15 multipurpose and diving vessels which are in operation were used.

Apparently from the schedules provided on figure 4 a certain regularity of change of weight loading of vessels under the articles of loadings of masses is traced. Having values of displacement of the designed vessel and being based on the statistical data reflected in schedules above according to (8) it is possible to define values of separate articles of loading of masses.

$$M_i = b * D - M / D \tag{8}$$

Here M_i – loading mass according to section (M_H, $M_{S,G.}$, M_{SYS}, $M_{P.P.}$, M_E, M_T, M_{Sp}, $M_{S.D.}$, $M_{L.M.}$, $M_{S.P.}$);

M_H – the hull mass;

$M_{S,G.}$ – the ship gear mass;

M_{SYS} – the ship system mass;

$M_{P.P.}$ – the propulsion plant mass;

M_E – the electrical systems mass;

M_T – the tools mass;

M_{Sp} – the spare parts;

$M_{S.D.}$ – the stock displacement;

$M_{L.M.}$ – the liquefied mass;

$M_{S.P.}$ – the supply and property;

D – displacement;

b – correlation coefficient the considering regularity of the considered ratios determined by formula (10);

M / D – ratios of loading mass according to section and displacement determined by formula (9).

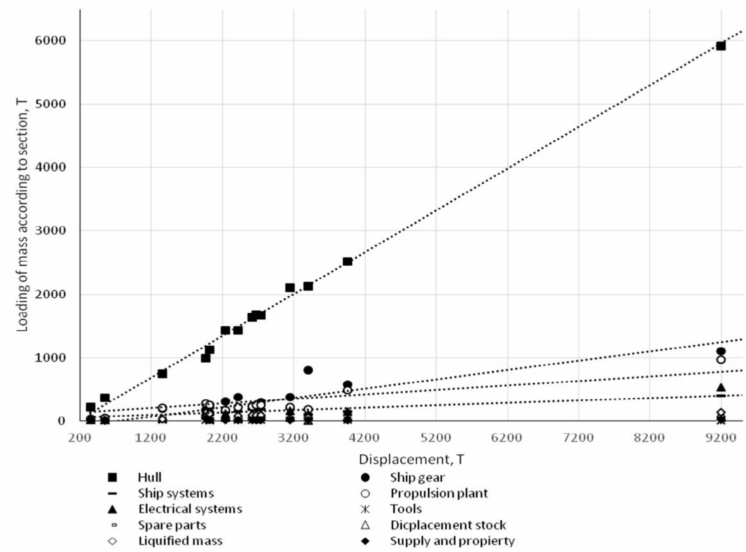

Fig. 4. Rating the loading of mass according to section and multipurpose vessel displacement

$$M / D = \sum_{i=1}^{n} M_i - b * \sum_{i=1}^{n} D_i \tag{9}$$

$$b = \frac{\sum_{i=1}^{n} (D - \bar{D}_i)(M - \bar{M}_i)}{\sqrt{\sum_{i=1}^{n} (D - \bar{D}_i)^2 \sum_{i=1}^{n} (M - \bar{M}_i)^2}} \tag{10}$$

Also predicted loadings of masses can be defined proceeding from statistical these loadings of the same vessels, in percentage terms from displacement. Similar methods were described by Ashik [2], for vessels of various class, (Passenger, cargo, timber carrying vessels, container, bulk, bulk-oil, trade and tows). In difference from the described vessels in Ashik's work as [2], in table 2. percentage of loadings of masses is specified being based on the statistical data of specialized courts.

Table 2

Structure of loading mass

№	The mass sections	Loading mass in %	
		max	min
01	Hull	66,8	50,47
02	Ship gear	23,45	3,46
03	Systems	10,36	3,8
04	Propulsion plant	17,55	5,18
05	Electrical systems	7,51	2,34
06	Tools	0,77	0,03
07	Spare parts	1,06	0,03
11	Displacement stock	7,64	0,02
12	Liquid mass	5,42	0,38
13	Supply and property	2,7	0,25

Thus, loading of mass of separate articles of displacement using characteristic structure in percentage terms it is possible to determine by formula 11

$$M_i = \frac{D \times m_i}{100} \tag{11}$$

Here m_i – percentage value of the relevant characteristic article of loading of masses.

Lower the schedules reflecting a difference of values of loadings of masses according to sections and calculated values on minimum and the maximum characteristic structure of loading of masses as a percentage are provided on figures 5-14.

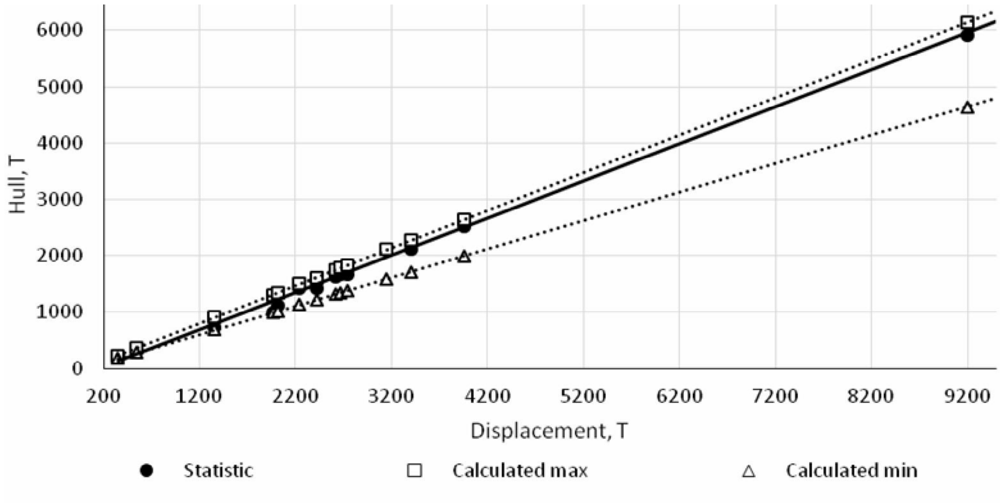

Fig. 5. The difference between the calculated and statistical ratio of mass of the hull and displacement of multipurpose vessel

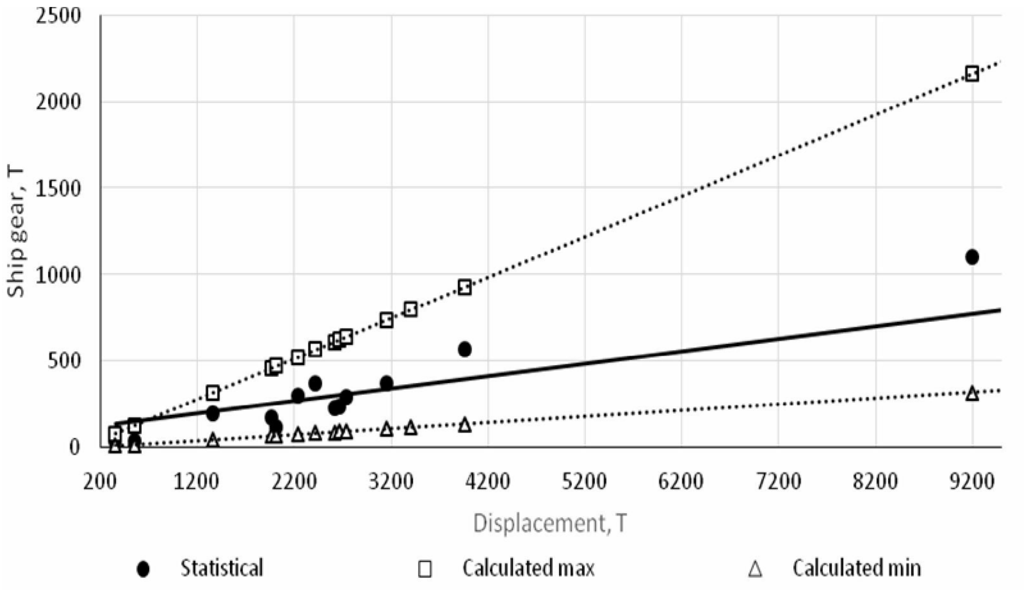

Fig. 6. The difference between the calculated and statistical ratio of mass of the ship gear and displacement of multipurpose vessel

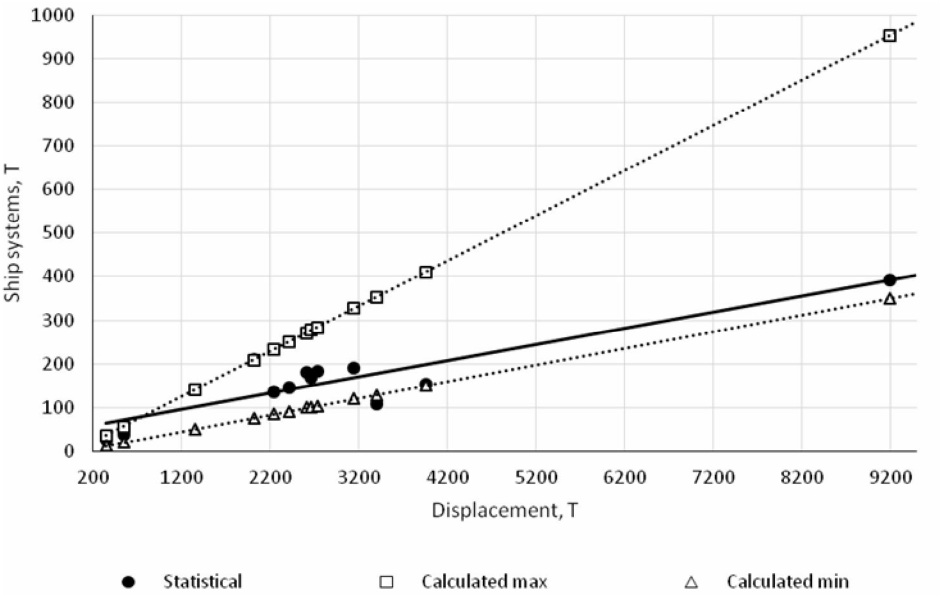

Fig. 7. The difference between the calculated and statistical ratio of mass of the ship systems and displacement of multipurpose vessel

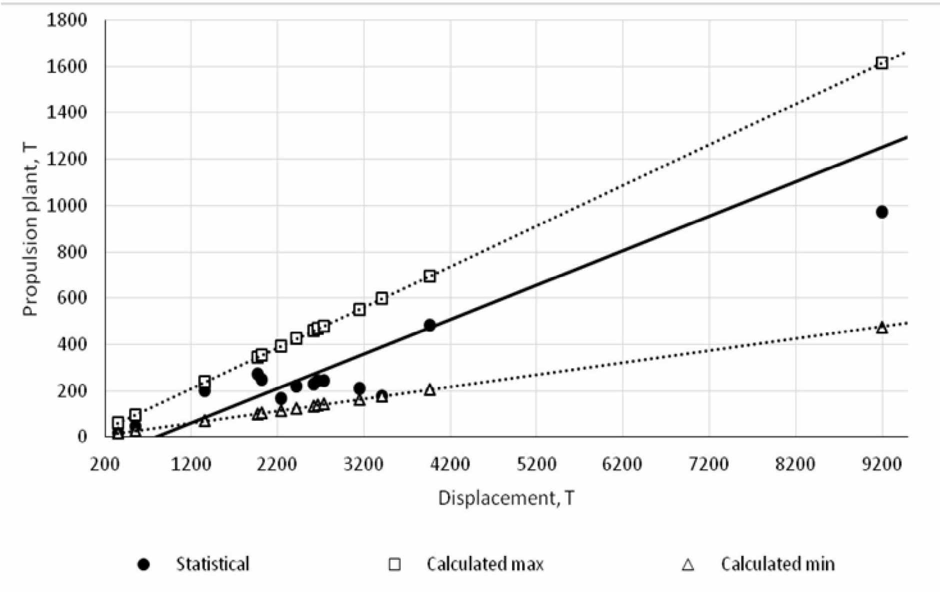

Fig. 8. The difference between the calculated and statistical ratio of mass of the propulsion plant and displacement of multipurpose vessel

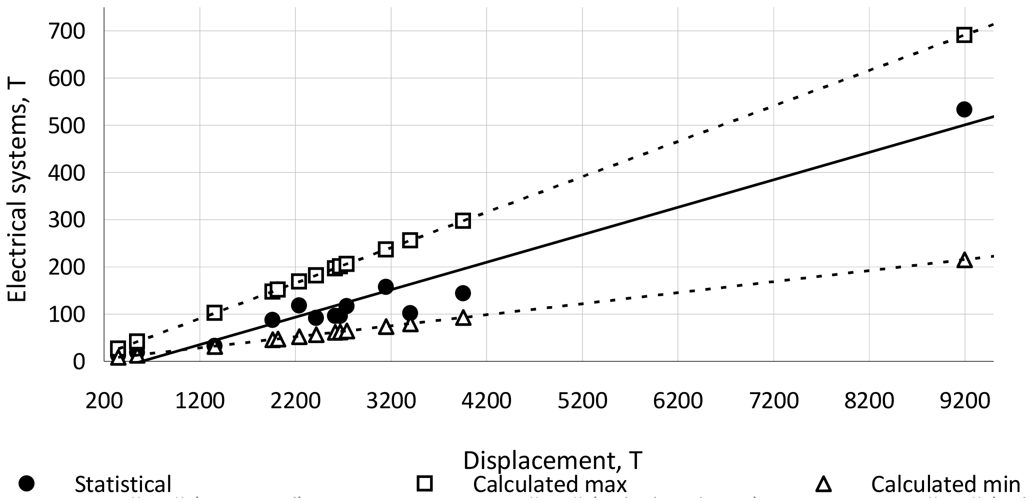

Fig. 9. The difference between the calculated and statistical ratio of mass of the electrical systems and displacement of multipurpose vessel

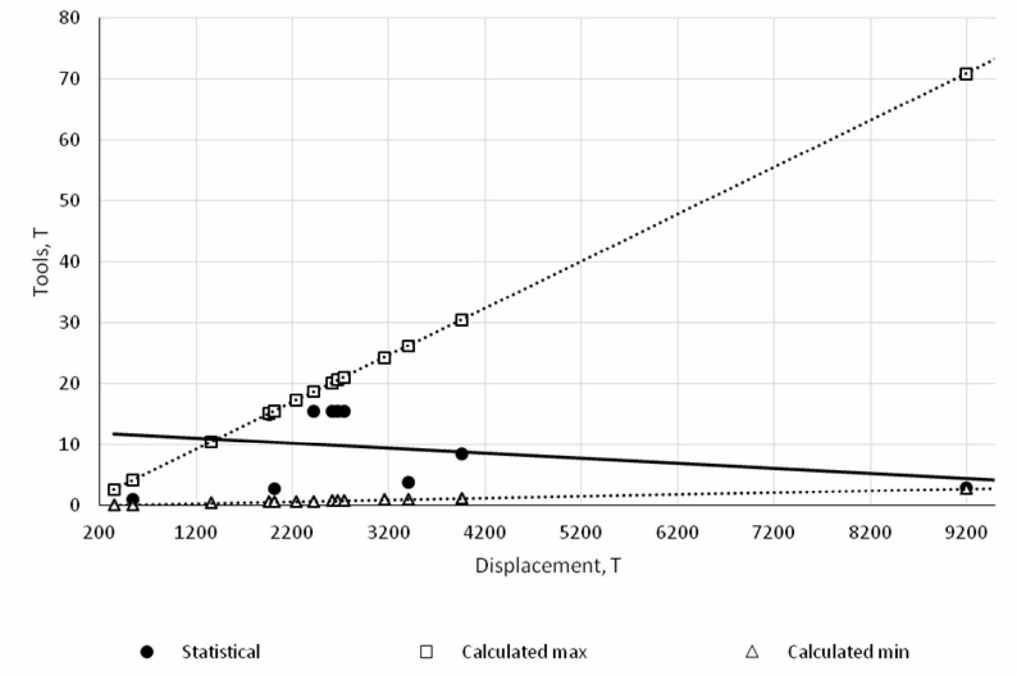

Fig. 10. The difference between the calculated and statistical ratio of mass of the tools and displacement of multipurpose vessel

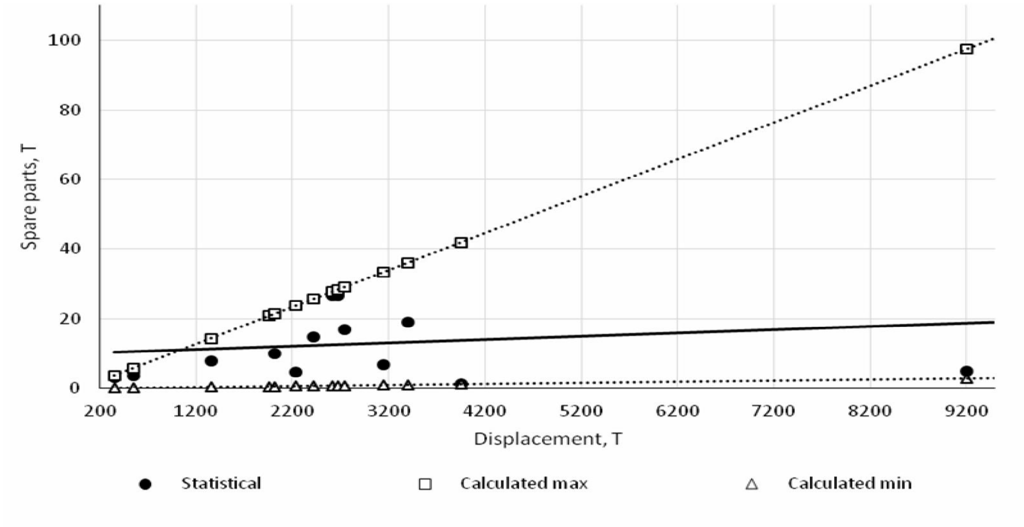

Fig. 11. The difference between the calculated and statistical ratio of mass of the spare parts and displacement of multipurpose vessel

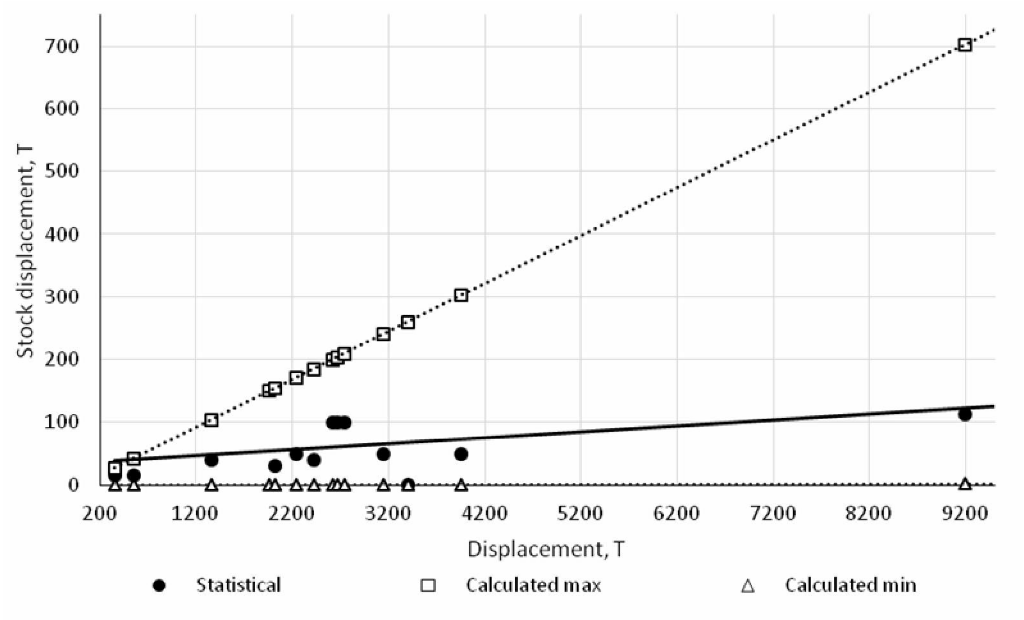

Fig. 12. The difference between the calculated and statistical ratio of mass of the stock displacement and displacement of multipurpose vessel

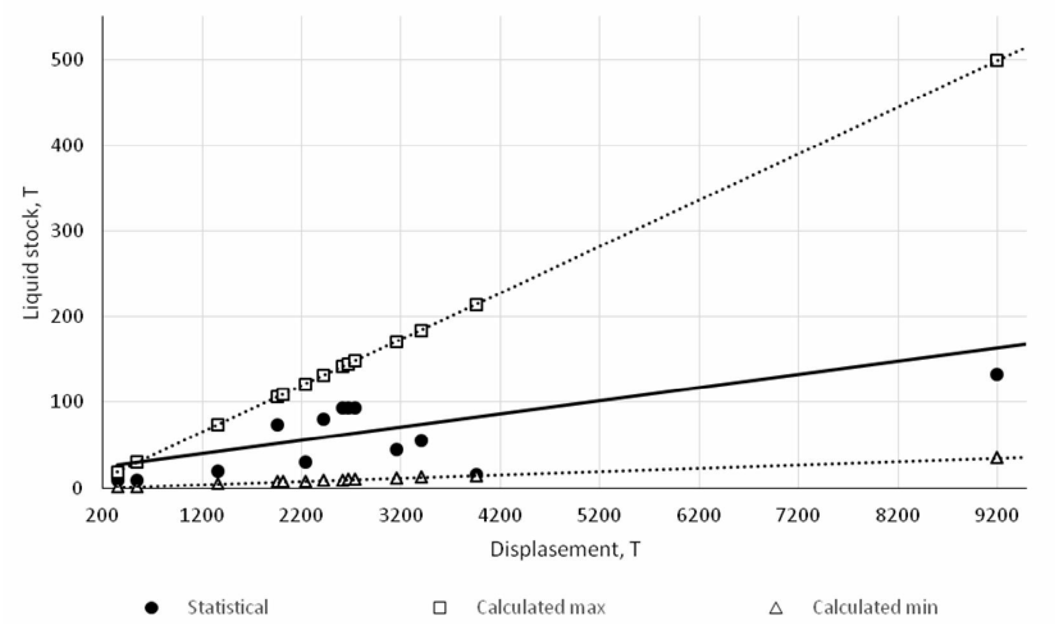

Fig. 13. The difference between the calculated and statistical ratio of mass of the liquid stock and displacement of multipurpose vessel

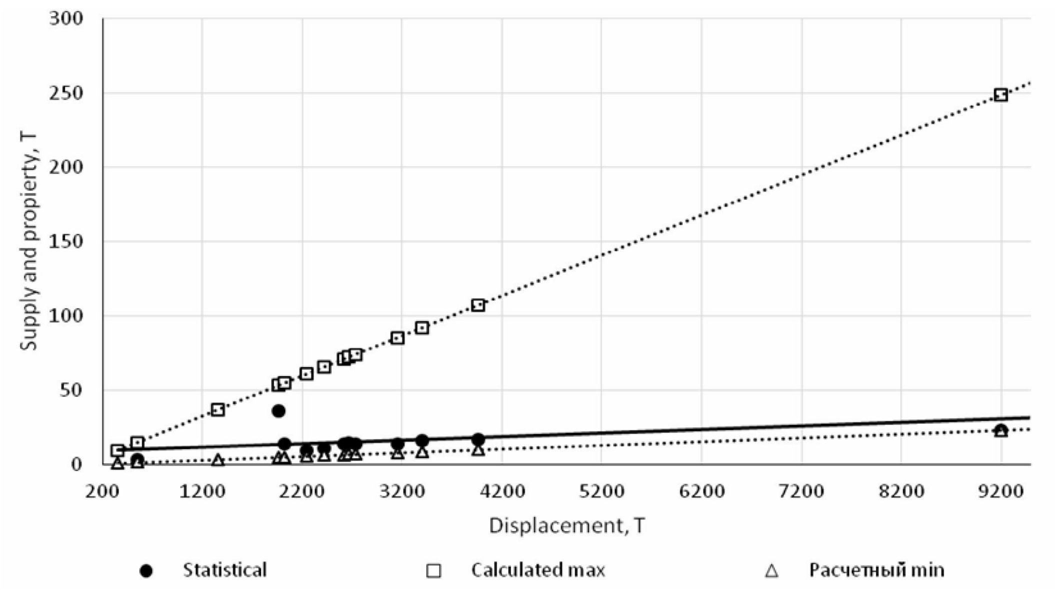

Fig. 14. The difference between the calculated and statistical ratio of mass of the supply and property and displacement of multipurpose vessel

Research of regularities of change of the main dimension and coefficient of completeness. The drawing up of the main dimensions of the subsea technical support vessels is closely related to the restrictions used in the design and present during the operation of the vessel.

Having calculated the width of the vessel, when determining the remaining dimensions, it is proposed to take into account the statistical data of the vessels in operation. Figures 15., 16. and 17. below show graphs of the ratios of the main dimensions of ships. When compiling the schedules, statistical data were used for 40 subsea construction vessels, 20 diving vessels, 24 ROV/AUV support vessel and on 18 MS support vessels.

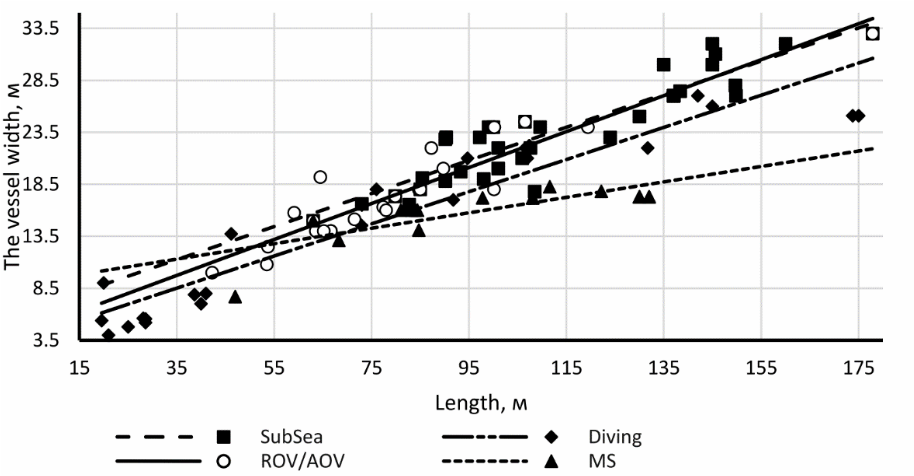

Fig. 15. Ratio of the vessel length and width (L/B)

Width of the hull of the designed vessel, connecting on ratios of width and length of the vessel by fig. 15 reflected in graphics, it is formed by formula (12)

$$B = b * L - B / L \quad (12)$$

Here B – the vessel width;

L – the vessel length;

b – correlation coefficient the considering regularity of the considered ratios determined by formula (14);

B / L – ratio the vessel length and width, determined by formula (13).

$$B / L = \sum_{i=1}^{n} \overline{B} - b * \sum_{i=1}^{n} L \quad (13)$$

$$b = \frac{\sum_{i=1}^{n} (L - \overline{L})(B - B_i)}{\sqrt{\sum_{i=1}^{n} (L - \overline{L})^2 \sum_{i=1}^{n} (B - \overline{B}_i)^2}} \quad (14)$$

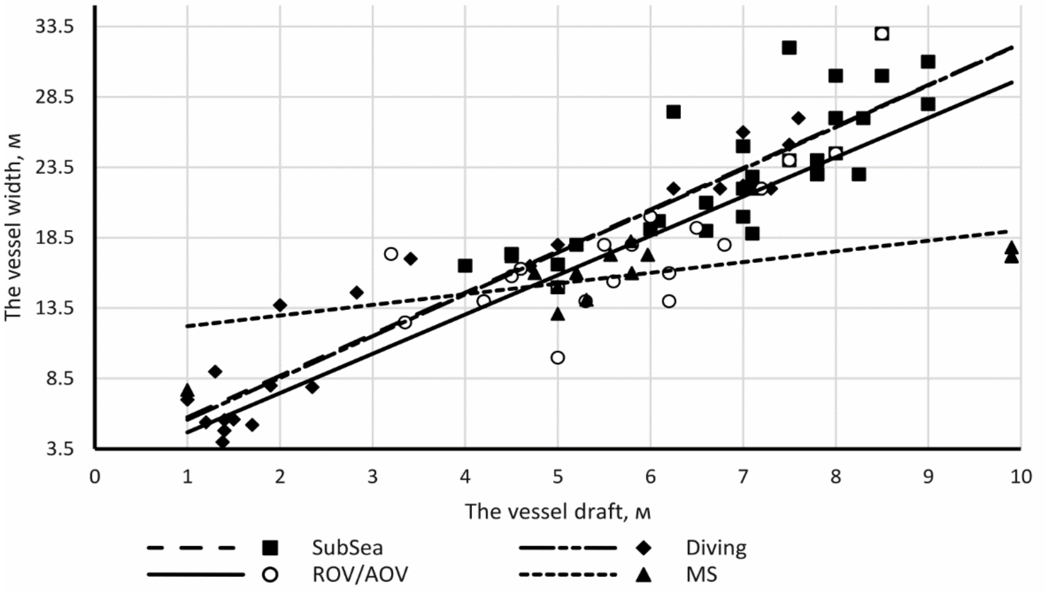

Fig. 16. Ratio of the vessel width and draft (B/T)

Considering the statistical data reflected in Figures 15 and 16, below in Table 3, the minimum and maximum statistical values of the ratios of the main dimensions and the block coefficient of fineness are given.

Table 3

The main dimension ratio

	L/B	B/T	δ
max	6,09	7,0	0,8
min	3,92	2,64	0,4

Width of the hull of the designed vessel, connecting with a ratio of width and draft of the vessel fig. 16 reflected in graphics, it can be formed by expression (15)

$$B = b * T - B / T \quad (15)$$

Here: T – the vessel draft;

b – correlation coefficient the considering regularity of the considered ratios determined by formula (17);

B / T – ratio the vessel width and draft, determined by formula (16).

$$B / T = \sum_{i=1}^{n} \overline{B} - b * \sum_{i=1}^{n} T \quad (16)$$

$$b = \frac{\sum_{i=1}^{n}(T-\overline{T})(B-\overline{B}_i)}{\sqrt{\sum_{i=1}^{n}(T-\overline{T})^2 \sum_{i=1}^{n}(B-\overline{B}_i)^2}} \qquad (17)$$

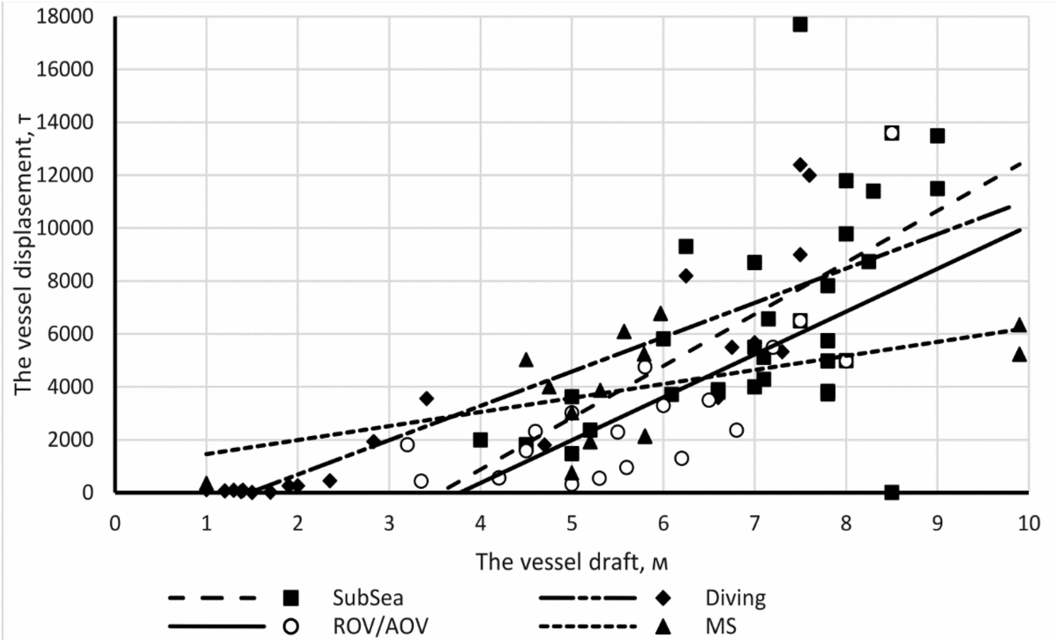

Fig. 17. The vessel draft and displacement ratio

The draft of the designed vessel, related to the ratio of draft and displacement of the vessel, is shown in the graph in fig. 17 can be expressed by formula (18):

$$T = b * T - T / D \ . \qquad (18)$$

Here D – the vessel displacement;

b – correlation coefficient the considering regularity of the considered ratios determined by formula (20);

T / D – ratio the vessel draft and displasement, determined by formula (19).

$$T / \mathrm{D} = \sum_{i=1}^{n} T - b * \sum_{i=1}^{n} D \ . \qquad (19)$$

In this case, the correlation coefficient is described by formula (20)

$$b = \frac{\sum_{i=1}^{n}(D-\bar{D})(T-\bar{T}_i)}{\sqrt{\sum_{i=1}^{n}(D-\bar{D})^2\sum_{i=1}^{n}(T-\bar{T}_i)^2}}. \quad (20)$$

When forming overall dimensions of the perspective vessel, optimum ratios of the main dimension, displacement and bloc coefficient of the general completeness influence formation of the optimum speed of the designed vessel shown in fig. 1.

The variable displacement, at constant overall dimensions of the designed vessel, influences on the vessel block coefficient. Changes of value of bloc coefficient of the vessel is reflected function (21)

$$\delta = (\text{const LBT})f(D) \quad (21)$$

Here δ – block coefficient;

(const LBT) – constant dimension of the vessel.

D – displacement.

At the same time, the connection between the block coefficient of the designed vessel with the overall dimensions and the required displacement is reflected in Figure 18.

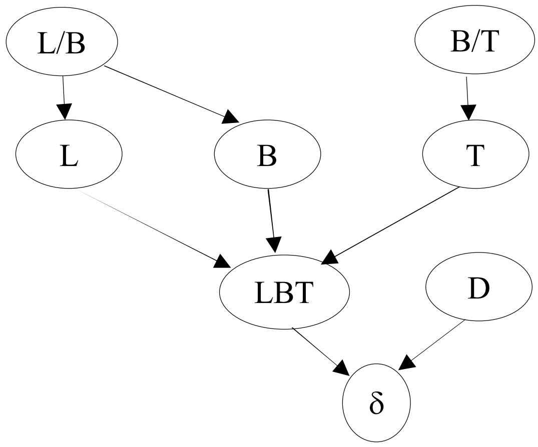

Fig. 18. Block coefficient graphic model

The width of the designed ship in this case is formed due to the functional connection between the length of the ship and the ratio of length and breadth (L / B) according to the statistical data of ships similar in type and is reflected in the formula (22)

$$B = \int f(L) = B(\frac{L}{B}) \quad (22)$$

In a similar way, the dimension of draft of the designed vessel is formed. In a case formation of the dimension of draft, in expression (23) is reflected functional communication of width of the vessel and a ratio of width and draft (B/T) according to statistical data of relatives on the type of vessel.

$$T = \int f(B) = T(\frac{B}{T}) \tag{23}$$

Considering graphic model in fig. 18., formula (22) and (23), formation of dimension of block coefficient is reflected in formula (24)

$$\delta_{(D)} = D / \int (f(L) \times B(L/B)) \times fT_{(B/T)} \tag{24}$$

The possibilities of calculating the width of a prospective vessel, considered above in formula (15), are considered subject to the availability of statistical data of vessels similar in purpose and in the absence of overall characteristics of the technological equipment used in the future. If there is information about the installed technological equipment and complexes, the relationship of factors involved in the formation of overall dimensions is reflected in the block diagram of Fig.19.

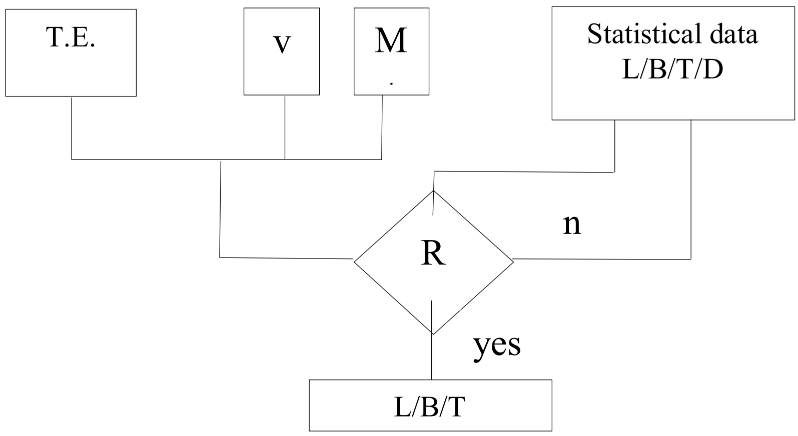

Fig. 19. The block diagram of formation of overall dimensions when using mobile operation equipment

The considered factors of influence of parameters of operation equipment, vessel speed and particulars of weight load of formation of the main dimension, taking into account the identified risks, is expressed by function (25):

$$L/B/T = Rf(T.E., v, M_i) \tag{25}$$

Here *R* – identification risk;

T.E. – operation equipment particulars;

M_i – load weight by section.

Conclusion. Conditions of influence of the main dimension on speed of the designed vessel and possibility of use of the main dimension in quality criterion of efficiency are investigated when forming a problem of optimization of speed of the perspective vessel.

A risk analysis was carried out taking into account the design constraints of the prospective vessel, with the main conclusions on the systems of proactive actions.

It is research regularity of change of articles of weight loading on specialized courts and the possibility of forecasting of weight loading at early design stages is defined.

Statistical data of ratios are research and the analysis of regularity of change of the main dimension of subsea construction vessels.

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