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Assessment of the stock of orders of the executor of ship repair works on the basis of labour balance

Present-day ship repair production is characterized by various work patterns, dynamics, work specialization, complexity and diversity of tasks, faced by management staff. Taking these peculiarities into account, one should not only hire personnel, but also plan the production activity of workers, which is impossible without the use of modern economic and mathematical methods. In particular, the use of the laws of labour balance contributes to a more realistic, objective planning, foresight of the failures in the implementation of the plans and adequate response to emergencies.

Ship-repair enterprises, labour intensity, power, labour balance, coordination.

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The practice of production planning and management uses the laws of different balances, including labour, finance, logistics, etc., at the level of common sense. The basic idea is very simple: you can't spend more than what you have. And if the physical laws of conservation of matter, energy, the impossibility of perpetual motion machines are accepted for use in practice without any doubt or psychological barriers, the laws of balances in industrial-economic activity often were and still are subjected to revision.

This tendency revealed itself to the greatest extent in the centralized administrative-command economic structures of socialistic era, when various plans for gross output, goods, sales, etc. were artificially raised (or lowered), and subjected to voluntary perturbations. A profound assessment of balances as inevitable economic laws contributes to a more realistic, objective planning, foresight of the failures in the implementation of the plans, the adequate response to their failures. All this remains true in the conditions of market economy.

That's why a clear and accurate presentation of balance theory and, in particular, the laws of labour balance, highlighted in this article, is considered relevant even at present, because it is an essential part of the methodology of planning and control in the economy.

When studying the organizational-technical characteristics of the ship repair company personnel one should bear in mind that labour intensity and the structure of vessel repair costs have significant fluctuations which depends on the constructive design of a ship, diversity of installed equipment and degree of deprecation of mechanisms and structures. At machine-building enterprises production is preceded by technical preparation, while at ship repair enterprises this preparation often ends up on the final stage. In addition, while providing high quality and low cost of the vessel repair, it is vital for ship-repair enterprises to ensure the minimum technologically acceptable timing from the start of the repair up to the release of a vessel. Essentially, this task can be solved if there is a clear system of all production resources (including labour) organization and management with the application of modern economic and mathematical methods.

"The availability of sufficient amount and quality of labour resources at an enterprise is determined by comparing the actual number of employees by categories and professions with the planned necessity" [6].

Labour balance is defined as the correlation between the required and available labour resources of a contractor for the planned time period while performing sets of works.

The basic concepts of labour balance include labour intensity of work (of a range of works), intensity (output), working capacity (labour resource) and the power capacity of the executor (output resource).

1. The labour intensity (or volume) of work is determined by the amount of working time in man-hours, which the contractor needs for the execution of the work. For example, if a lathe operator needs 3.2 man-hours to lathe a part on a machine-tool this is the labour intensity of the work. Labour intensity is one of the characteristics of a work (operation), which is determined by many factors (content, executor's qualification, grade, the name and value of the material, etc.).

Planned and record labour intensity is measured by standardized time, i.e. the time which an executor must spend on the work in compliance with the enterprises' standards (measured in standard hours – s.h.). Standards are based on statistical processing of respective observations.

Due to the fact that technical progress changes the amount of standardized time quite rapidly, the standardized time fixed on a certain date, for instance, Jamuary 1, 2010 is used to measure planned labour costs.

Such standards are called conditionally-constant. They are used when making an estimate, and the measuring unit is called estimated standard hour or estimated hour (est.h.). The estimated labour intensity is reviewed not so frequently as the standardized labour intensity, and the emerging gap is a legitimate source of an executor's additional income – as a result of improved technology and work organization.

There are other ways of making up and studying an estimate but they are based on the values proportional to the estimated labour intensity: for example, the measurement of the standard cost of the work for one estimated hour or in team-days, etc. In the present study an estimated hour will be used as a measurement unit of labour intensity.

If the full labour intensity of the performance of the work is Q_m est. h., for example Q_m = 50 thousand est. h., then an executor reaches this figure during a certain time period T (days).

If Q est.h. is the interim volume of work, completed by a certain moment of time $t < T$, then this volume Q should increase from

0 to Q_m, being a certain non-decreasing function of time, reflecting the cumulative total of the executor's work.

$$Q = Q(t) \quad (1)$$

The function (1) can be represented analytically or in the form of a graph or a table.

If, for example, the volume of $Q_m = 50\,000$ est.h. is coped with according to the law[1] $Q = 5t^2$,

where Q is measured in thousands est. h.,

t is the time in days (the example is fictional).

Then all the works listed in the estimate will be completed for the time $T = \sqrt{Qm/5} = 100$ days. The function Q is presented in *table 1* and on the graph *(fig. 1)*.

Sometimes it is useful to present the function (1) in relative coordinates (in percent). In this case, the relationship between the absolute values of t and Q and a relative is expressed by the formulae:

$$\bar{t} = \frac{t}{T} \times 100\%, \quad \bar{Q} = \frac{Q}{Qm} \times 100\% \quad (2)$$

Table 2 presents the fulfillment of the volume of works on the object from the example in table 1 – on a percentage base. In *figure 2* there is a graph, corresponding to table 2.

2. Output or intensity of the fulfillment of the volume is defined as the rate of labour intensity change and is introduced as any rate of change of the function.

Table 1. Completion of works on an object

t, days	0,0	10	20	30	40	50	60	70	80	90	100
Q, thousands of est.h.	0,0	0,5	2	4,5	8,0	12,5	18,0	24,5	32,0	40,5	50,0

Figure 1. Graph representing the fulfillment of the volume of works on the object

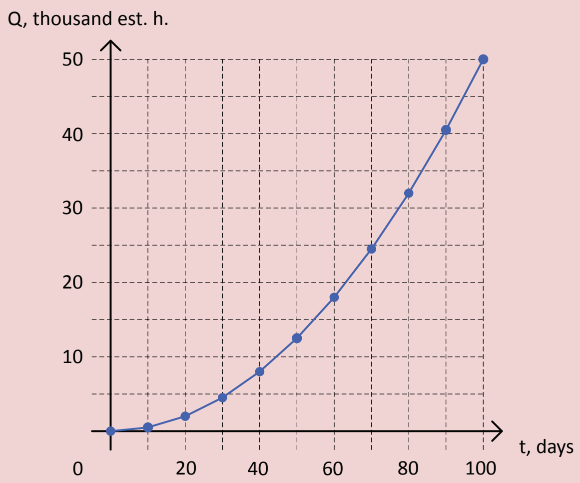
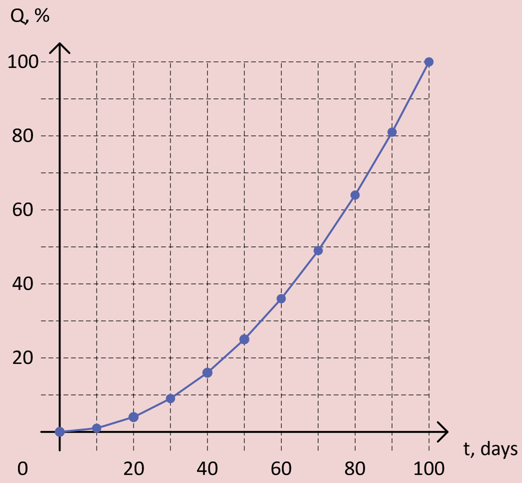


Table 2. Fulfillment of the volume of works on the object on a percentage base

$\bar{t}$, %	0,0	10	20	30	40	50	60	70	80	90	100
$\bar{Q}$, %	0,0	1	4	9	16	25	36	49	64	81	100

[1] Strictly speaking, the fuiction Q(t) is not continuous, however, it is convenient to represent it as a continuous function like in the given example

Figure 2. Graph representing the fulfillment of the volume on a percentage base



If the developed volume at a moment of time t is Q est. h., at the moment of time t_1 it is t + Δt, respectively $Q_1 = Q + \Delta Q$ est. h. Then the average speed q_{av} of the development of the volume of the Δt days is:

$$q_{av} = \frac{\Delta Q}{\Delta t} \qquad (3)$$

The speed q of the fulfillment of the volume at a given moment can be essentially called the limit:

$$q = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} \quad \text{or} \quad q = \frac{dQ}{dt} \qquad (4)$$

The intensity of the fulfillment of the volume (production output) at a given moment is the derivative of the fulfilled volume with respect to time. It is measured in est. h./day.

The formula (4) creates the link

$$Q = \int_{t_1}^{t_2} q dt \qquad (5)$$

The integral (5) can be expressed as area under the curve q = q(t) on the interval $[t_1, t_2]$, if we know the scale. For example, for the function of the fulfillment of the volume $Q = 5t^2$ speed of development (output) is $q = {dQ}/{dt} = 10t$ est. h./day.

The corresponding graph is shown in *figure 3*.

The volume of works, fulfilled from the commencement of works for 50 days will equal

$$Q_{0-50} = \int_0^{50} 10t dt = 5t^2 \Big|_0^{50} = 12500 \ \text{(est. h.)}.$$

The volume of works, fulfilled over time from t = 50 up to t = 80: will equal

$$Q_{50-80} = \int_{50}^{80} 10t dt = 5t^2 \Big|_{50}^{80} = 19500 \ \text{(est. h.)}.$$

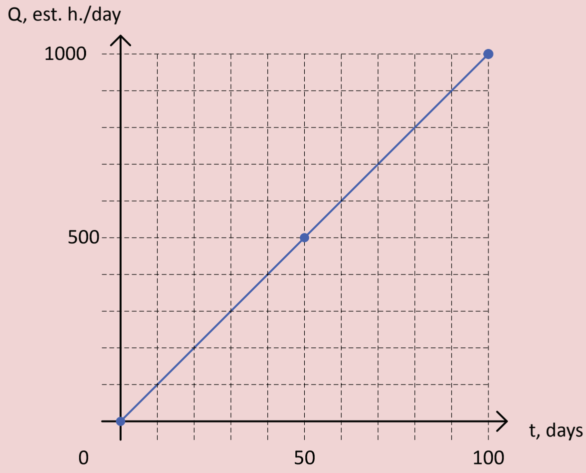
The actual dependence of the output on the time (for the repair of a vessel), as a rule, can't be described with the help of "neat" formulas, so numerical and numerical-graphic methods are used for the transition from volumes to the outputs and vice versa [4]. Diagrams q = q (t) is referred to as distribution diagrams of workload.

A special role in the planning belongs to the average daily output, which is the relation of the full volume of work Qm on the object to the full time T of execution of the whole range of works:

$$q_{av} = \frac{Qm}{T} \qquad (6)$$

The relation (6) generates two widely used formulae:

Figure 3. Graph representing the changes in output on the object q = 10t



$$T = {}^{Qm}\!/_{q_{av}} \tag{7}$$

$$Q_m = q_{av} \times T \tag{8}$$

Formula (7), in particular, implies that the ultimate reduction of a vessel's repair duration (item manufacture) is determined by the ultimate increase in the value q_{av}.

3. Working capacity (resource by volume) A of an executor of work for a certain time period t is the greatest labour intensity which he/she is capable of providing for this time period. An executor can be one person, team, shop, factory, etc. Working capacity A is measured in the estimate hours and forms a non-decreasing function of time:

$$A = A(t) \tag{9}$$

The function (9) can be represented analytically or in the form of a graph or a table.

For example, the number of actually present multiple-skill crew workers according to the schedule is specified in *table 3.*

If the average daily output per one worker is 10 est. h./day, then the daily working capacity of a crew can be stated in table 4, the second line.

The third line presents the working capacity of a crew (cumulative) in a function of time. *Figure 4* shows working capacity of a crew, corresponding with *table 4.*

4. The average power of an executor for a certain period of time Δt is the ratio:

$$N_{av} = \frac{\Delta A}{\Delta t} \tag{10}$$

The power (power resource) of an executor at a certain moment is the limit:

$$N = \lim_{\Delta t \to 0} N_{av} \quad \text{or} \quad N = \frac{dA}{dt} \tag{11}$$

The power of an executor at a certain moment is the derivative of his/her working capacity with time. The power is measured in est. h./day.

The formula (11) shows an obvious relation:

$$A = \int_{t_1}^{t_2} N dt \tag{12}$$

In practice, when creating the function of power, numerical and numerical-graphic methods are also used.

On the basis of the main concepts of labour balance stated above, the laws of labour balance can be formulated.

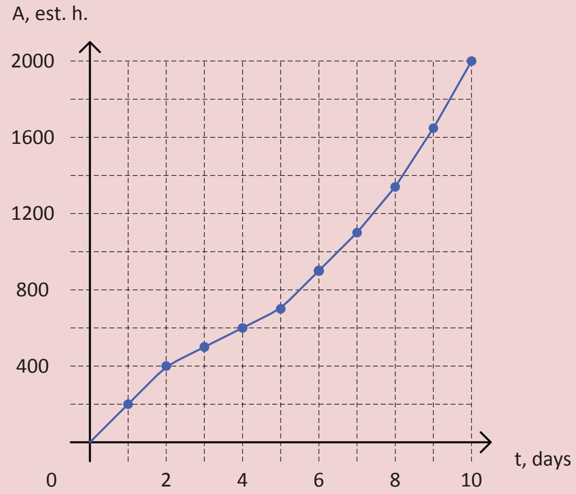
Table 3. the number of actually present crew on an object

Ordinal days	1	2	3	4	5	6	7	8	9	10
Number of workers actually present	20	20	10	10	10	20	20	25	30	35

Table 4. Working capacity as displayed in a table

Ordinal days i	1	2	3	4	5	6	7	8	9	10
ΔA_i est.h.	200	200	100	100	100	200	200	250	300	350
A_i est.h.	200	400	500	600	700	900	1100	1350	1650	2000

Figure 4. Graph representing the function of working capacity



If an executor whose working capacity and power are characterized by the functions A (t) and N (t) respectively, carries out a work (a range of works), the labour intensity and output of which is described, respectively, with the functions Q (t) and q (t), then, for the given values the following laws (axioms) of labour balance are true.

I law. In any interval of time the increment of actually fulfilled labour intensity may not be larger than the increment of the executor's working capacity:

$$\Delta Q \leq \Delta A \quad (13)$$

The formula (13) can look differently:

$$\int_{t_1}^{t_2} q dt \leq \int_{t_1}^{t_2} N dt \quad (14)$$

II law. In any moment of time the actual output of the executor can not exceed his/her power:

$$q \leq N \quad (15)$$

It is noteworthy that the first law can be derived from the second law. However, both laws should be formulated since each of them has its own value.

III law. If a range of works carried out by the executor has total labour intensity (volume) of Q_m, then the total labour intensity of the works does not depend on the intensity of their execution and, other factors being equal, remains constant.

So, for example, the total labour intensity of the inter-voyage ship repair will remain the same no matter how many crews or which one of them repairs the vessel.

If Q_{m1} and Q_{m2} are full volumes of the same complex of works with different ways of organizing this complex (types of network schedule), then the mathematical expression of the third law is as follows:

$$Q_{m1} = Q_{m2} \qquad (16)$$

IV law. The intensity (output) in the execution of work (a complex of works) in each moment of time is limited from above:

$$q \le q_{max} \qquad (17)$$

The value of q_{max} depends on the state of the object, and therefore the approach to its assessment should not be formal. A few remarks should be made.

Firstly, it is necessary to note, that the laws of labour balance are akin to the laws of nature, and in contrast to the legal laws, they cannot be altered or cancelled. Knowledge of these laws makes it possible to resolve conflicts between the customer and the executor concerning the volumes and timing of the execution of the stock of orders and helps to anticipate the possible under- and overloading of the executor with the work.

Secondly, the formulated laws express only the necessary (but not sufficient) conditions of the feasibility of the plans. The implementation of a plan depends largely on the balance of finances, logistical support, selected specialties and on a wide range of random factors. However, it can be argued that any plans are inevitably doomed to failure, if they contradict the laws of labour balance.

As a rule, relations, expressing the laws of labour balance, deal with average values, which manifest themselves best of all on a large scale. So, the larger the enterprise, the facilities and the range of works, the more reliable is the application of the formula stated above. In particular, this refers to provision of services to ship owners in cluster forms.

Application of the laws of labour balance can be demonstrated on the example of the order backlog analysis.

The following situation can be considered as an example. A list of ships subject to dock repair in the planning period of six months, from July 1 to December 31 of a conditional year, is given in the consolidated application *(tab. 5)*. The average monthly capacity of a dock production, stated in the section “Dock repair of the vessels”, equals N = 48.0 thousand est. h./month[2]. Consequently, the working capacity of the production in the planning period is A=48 x 6=288.0 thousand est. h.

Table 5 consists of two parts. The first part contains the application for the docking of vessels undergoing the scheduled - average - major repair. The second part contains the vessels subject to extended inter-voyage ship maintenance (EIVSM) between scheduled repairs.

Column 3 (volume) is compiled with a different degree of accuracy: from almost accurate data for the ships waiting for the second docking with defects already detected, to the predictive data, based on statistics and expert opinions.

Columns 4 and 5 for the ships awaiting scheduled repair are complied on the basis of extended network schedules of this repair or the experts’ conclusions.

For vessels undergoing EIVSM, these columns are filled in cooperation with ship owners according to the results of the of EIVSM schedules analysis. Column 6 contains the adopted normative average daily output for each combination “vessel type –type of repair”.

Column 7 is calculated by the formula (6):

$$T = {}^{Qm}\!\!\diagup_{qH}\,.$$

[2] Actually, the working capacity is calculated for each month separately, depending on the number of working days in a month and some other factors; however, the round up is methodologically justified here and it doesn’t interfere with the logic of the analysis.

Table 5. Consolidated application for the docking of vessels in the second half of the year

№	Name of a vessel (hull number)	Expected volume of dock repair. thousand est. h. Q_m	Earliest date of the beginning of docking	Latest date of the end of dock repair	Normative output. est. h./day q_n	Planned duration of docking T	Note
1	2	3	4	5	6	7	8
I. Dock repair as a part of general scheduled (average) repair							
1.1. Large fishing freezer trawlers (LFFT) project X							
1.	LFFT-0100	30.0	01.07	09.09	500	60	II docking
2.	LFFT-2300	27.0	01.07	11.10	500	54	II docking
3.	LFFT-3200	25.6	01.10	18.01	500	51	
1.2. LFFT project Y							
4.	LFFT-9110	16.0	01.07	10.09	480	33	II docking
5.	LFFT-9120	8.0	01.08	15.02	480	17	
1.3. Wet-fish trawlers (WFT)							
6.	WFT-1135	3.0	-	10.07	400	8	Volume. remaining from the 1st half-year
7.	WFT-1121	8.5	01.07	20.08	400	21	II docking
8.	WFT-1133	7.2	01.07	03.09	400	18	II docking
9.	WFT-1138	8.9	15.08	14.11	400	22	II docking
10.	WFT-1141	8.0	15.09	30.12	400	20	
11.	WFT-1124	8.0	01.11	02.02	400	20	
II. Dock repair as a part of extended inter-voyage ship maintenance (EIVSM)							
2.1. Large autonomous trawlers (LAT)							
12.	LAT-0001	16.0	-	08.08	550	29	Volume. remaining from the 1st half-year
13.	LAT-0012	19.0	12.08	12.10	550	35	
14.	LAT-0024	19.0	01.09	01.11	550	35	
15.	LAT-0017	19.0	17.10	17.12	550	35	
2.2. LFFT project X							
16.	LFFT-2200	4.2	-	30.07	420	10	Volume. remaining from the 1st half-year.
17.	LFFT-2400	6.8	01.07	10.08	420	16	
18.	LFFT-3000	6.8	20.08	29.09	420	16	
19.	LFFT-2500	6.8	20.10	05.12	420	16	
20.	LFFT-1800	6.8	30.10	10.01	420	16	
2.3. LFFT project Y							
21.	LFFT-9150	5.4	05.07	15.08	370	15	
22.	LFFT-9170	5.4	08.10	22.11	370	15	
23.	LFFT-9112	5.4	20.12	16.02	370	15	
2.4. WFT							
24.	WFT-1132	4.4	01.07	06.08	300	15	
25.	WFT-1126	4.4	20.07	29.08	300	15	
26.	WFT-1127	4.4	01.08	10.09	300	15	
27.	WFT-1118	4.4	27.07	13.09	300	15	
28.	WFT-1112	4.4	01.08	20.09	300	15	
29.	WFT-1133	4.4	05.09	13.10	300	15	
30.	WFT-1135	4.4	30.11	04.01	300	15	
31.	WFT-1120	4.4	25.10	06.12	300	15	

Table 6, based on the data from table 5, represents a line graph of reported and passing vessels docking, where 2 lines are pointed out next to each vessel number.

The dotted line represents the time interval from the moment of the allowable early start of the vessel's dock repair till the moment of the allowable latest time of the vessel's dock repair completion.

The solid line represents the normative period of docking time, oriented towards the latest available timing (hence the name of the table – Option "L" – "late").

The volume of forthcoming works for each vessel in each month is distributed along this segment. The corresponding figures are indicated in the upper left corner of the cells. These (rounded) figures were obtained by multiplication of normative output by the corresponding number of days. So, for example, a vessel №1 is undergoing the repair for 21 days in July, 31days in August and 8 days in September. Regulatory output for this vessel (see table 5) is 500 est. h./day. Thus, 500 x 21 = 10.500 est. h. in July. 500 x 31 = 15.500 est. h. in August and 30.000 – 10.500 – 1.500 = 4.000 est. h. in September.

When fulfilling labour intensity per a vessel, the daily output, generally speaking, will not be permanent. The given volume of works can be carried out differently. Therefore, monthly layout of the total amount of works on a ship can be quite random.

However, the sum of figures horizontally for each vessel should converge to the total volume (III law of labour balance).

The output within each period of a vessel's repair is also limited (the fourth law).

The end of table 6 presents: the increment in the total work-load for months ΔQ, as well as the overall work-load of dock production on a cumulative total Q. In addition, the table shows the increment in working capacity (resource) by months ΔA = 48.0 thousand, est. h. and it is also shown on a cumulative total A.

First of all, it can be seen that for six months the total workload at the orientation towards the later date is Q^L = 271.5 thousand est. h., the resource A = 288.0 thousand est. h. (the "L" stands for "late"). Thus: $Q^L < A$ that does not conflict with the first law of labour balance. This means that for six months all vessels, with accuracy to the volumes transferred to the following year, can be repaired.

However, overloads appeared within the planned half-year. So, during the first two months the resource will equal 96 thousand est. h., the workload Q = 105.3 thousand est. h., that conflicts with the first axiom. So, 105.3 – 96.0 = 9.3 thousand est. h will be transferred to a third planned month (i.e. September) (the third axiom). Such a phenomenon (overload) will take place until the end of the fourth month of the first half-year, and only in the fifth month of the second half-year, in November, all the planned volume for the vessels will be fulfilled. This fact should be taken into account in advance and the deadlines for completion of least-priority vessels docking should be shifted in accordance with the need of balancing the orders (applications) backlog (it isn't done in the present article).

In any case, it is necessary to be prepared in advance to the fact that, because of the overload, starting in August, the deadlines could be missed; if the prolongation of vessels dock repair is not managed purposefully, it will begin spontaneously: the laws of labour balance are inexorable.

These are the first results of the simplest analysis of an orders backlog.

One more important question is easy to answer: is the underloading, incomplete use of labour resources, connected with the corresponding loss of volume?

Such a possibility should be checked for July, November and December, for which $A - Q^L > 0$. Without a detailed analysis it is evident that there are several options of «shifting» to the left the line segments, representing the timing

Table 6. A line graph of docking. Option "L"

Vessel number	Volume, thsd. est. h.	Duration, days	Scheduled period						Next period
			VII	VIII	IX	X	XI	XII	
1	2	3	4	5	6	7	8	9	10
1	30.0	60	10.5	15.5	4.0 9				
2	27.0	54		7.5	14.5	5.0 11			
3	26.0	51			1		2.0	15.5	8.5 18.01
4	16.0	33		11.2	4.8 10				
5	8.0	17	1						8.0 15.02
6	3.0	8	3.0 10						
7	8.5	21	0.4	8.1 20					
8	7.2	18		6.2	1.2 3				
9	8.9	22		12		4.1	4.8 14		
10	8.0	20			15			8.0	30
11	8.0	20				1			8.0 02.02
12	16.0	29	11.6	4.4 8					
13	19.0	35		12	12.4	6.6 12			
14	19.0	35		1	3.0	16.0	1		
15	19.0	35				17	9.6	9.6 17	
16	4.2	10	4.2	30					
17	6.8	16	2.6	4.2 10					
18	6.8	16		20	6.8	29			
19	6.8	16				20	4.7	2.1 5	
20	6.8	16				30		2.6	4.2 10.01
21	5.4	15	5	5.4 15					
22	5.4	15				8	5.4 22		
23	5.4	15						20	5.4 16.02
24	4.4	15	2.6	1.8 6					
25	4.4	15	20	4.4	29				
26	4.4	15	1	1.4	3.0 10				
27	4.4	15	27	0.5	3.9 13				
28	4.4	15	1		4.4 20				
29	4.4	15			5 0.8	3.6 13			
30	4.4	15					30	3.6	0.8 14.01
31	4.4	15				25	2.6	1.8 6	
Totally, for months		Δ Qп	34.9	70.4	58.8	35.3	29.1	43.0	34.0
Progressive total		Qп	34.9	105.3	164.1	199.4	228.5	271.5	306.4
Working capacity for months		Δ A	48.0	48.0	48.0	48.0	48.0	48.0	
Progressive total		A	48.0	96.0	144.0	192.0	240.0	288.0	

of the vessels dock repair, when the amounts to be fulfilled will pass from August to July. For full loading of July $A - Q^L = 48.0 - 34.9 = 13.1$ thousand est. h. should be added. For this purpose, it will be enough to shift the repair of the vessel No. 7 (8.1 thousand est. h.) to July, and also, for example, to redistribute the volume for the vessel No. 21 (5.0 thousand est. h. – on July, and leave 0.4 thousand est. h. for August). The total supplement for July will be 8.1 + 5.0 = 13.1 thousand est. h. Of course, this task can be solved in a different way. Most likely, it will be enough to content oneself with the idea that in July there are no problems concerning the workload, and the question about the specific vessels awaiting the repair, should be left for operative decisions. This idea is emphasized here because it is considered essential. This is how, in particular, the principle of a flexible planning reveals itself.

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