

The life cycle of a passenger ship consists of such stages as designing, construction, operation, modernization, and disposal. Modernization includes a certain variety of operations on the vessel upgrading and thus contributes to the extension of the vessel life cycle. It is possible to determine the types, scope, and cost of operations for each vessel under consideration after analyzing its technical condition. It is advisable to alternate the operations of direct and indirect influence on the would-be profit from vessel operation when compiling a list of necessary modernization operations. Those vessels that as a result of preliminary calculations will not bring profit after modernization should not be included in the modernization plan.

Modernization is not able to replace shipbuilding as the main way to renew the fleet. However, under conditions of limited monetary funds, it should be used to smooth the need for new vessels.

The optimal distribution of funds between the groups of operations on vessel modernization was determined using a mathematical model. Objective function maximizes the profit gain from modernization operations. The controlled system in this case is a passenger ship. The state of the system before each step is characterized by the number of still undistributed funds. As a result of solving the problem, a shipowner receives an answer regarding the amount of funds available for him, the groups of operations on the passenger ship modernization in which to invest to have the highest profit gain.

Thus, the strategy of modernization of passenger ships by optimal distribution of funds is based on determining the types and volume of operations, their cost, utility, the ability to gain profit from the operation of a modernized vessel. It is also based on the optimization problem of allocating funds to modernization, provided they are limited

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DEVELOPING A STRATEGY FOR MODERNIZING PASSENGER SHIPS BY THE OPTIMAL DISTRIBUTION OF FUNDS

A. Shibaev

Doctor of Technical Sciences, Professor*

E-mail: aleksshibaev54@gmail.com

S. Borovyk

Senior Lecturer*

E-mail: svetlanasborovik@gmail.com

Iu. Mykhailova

PhD, Associate Professor

Department of Entrepreneurship and Tourism**

E-mail: yuliya.mikhailova@mail.ru

*Department of Fleet Operation and Marine Transportation Technology**

**Odessa National Maritime University

Mechnikova str., 34, Odessa, Ukraine, 65029

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1. Introduction

In recent decades, the volume of the market for passenger transportation by water has tended to increase. This was mainly due to the development of tourism with the relatively stable linear transport market. As a result of the introduction of quarantine measures to overcome the pandemic, passenger traffic and the flow of tourists using water transport have significantly decreased. The owners of large cruise vessels have been hit hardest by the imposition of restrictions on international air travel, the impossibility to enforce quarantine measures on vessels with a passenger capacity of more than 1,500 people, etc. However, small-capacity vessels continue to operate, particularly, on inland waterways. Passenger transportation on sea lines is also being carried out.

Population mobility is expected to increase after the removal of quarantine measures. There will also be a significant increase in demand for water passenger transport services, especially among tourists, due to the effect of delayed demand.

A shipping company can ensure its competitive advantage in the passenger transport market by providing high-quality passenger transportation service. In today's environment of fierce competition with other modes of

transport, vessel owners operating the passenger fleet face the problem of attracting passengers. The specifics of the operation of passenger ships implies the fact that a shipowner needs to take into consideration the requirements to ensure the comfort of passengers. For passengers, the ability of a shipping company to provide a high-quality service at an affordable price serves as the efficiency criteria. And this can be done only if there is a technically faultless, safe, and comfortable fleet.

The problem of the distribution of resources (monetary funds) has been and remains relevant and addressed at present, regardless of the types of production. It is of particular importance for passenger ships, as it must provide for a certain transport process and appropriate comfort.

Passenger ships are known to be in better technical condition, compared to cargo vessels, however, they are prone to increased wear of cabins and public premises.

In most cases, decisions to execute the types of modernization operations are made if there is a necessity. The sequence, in this case, is as follows: the composition, volume, and cost of operations are determined; the effectiveness of the investment in modernization is assessed. Evaluation of the investment effectiveness is based on the models and methods of linear programming or, often, return on invest-

ment. At the same time, the ship owner's funds for the modernization of technical equipment and bringing them to a technically appropriate state are usually limited. In order to achieve the highest efficiency of modernization, it is required to use a decision-making method that is appropriate to the facility and the conditions.

In the context of the global economic crisis and limited funds that a shipowner can direct to the development of his activity, the problem of enhancing the modernization efficiency is urgent and requires constant study. The ever-changing operating conditions of transport facilities necessitate the development of new approaches to the improvement of modernization efficiency, adequate to real production situations.

2. Literature review and problem statement

In paper [1], modernization is considered as one of the effective ways to upgrade the fleet and thus extend the vessels' LC. Modernization of a hull, engines, and machinery, electrical equipment makes it possible to extend the service life of a vessel for the period planned by a shipowner under certain technical conditions. The validity of this assertion is evidenced by the results of the study presented in paper [2]. It is certain that new vessels have faults and failures of systems as often as the old modernized ones. This is due to the fact that the operation of vessels built by new technologies requires a new level of training specialists. The rapid modernization of the small-tonnage fleet due to the construction of new vessels may lead to more frequent failures due to inadequate maintenance related to the low skills of a crew. Modernization will make it possible to stretch in time the renewal of the small-tonnage fleet with the help of shipbuilding, thus providing an opportunity to improve the skills of the command staff. However, the operation of a morally and technically obsolete fleet will be ineffective.

Thus, there arises a need to find the optimal strategy of planning purchasing, maintenance organization, factory planned and unplanned repairs, to keep vessels in good working order, and timely decommissioning of inefficient vessels. To solve the set problem, a mathematical model, which makes it possible to track changes in the average number of fleet vessels at different stages of their LC, such as construction, operation, repair, and disposal, was developed in paper [3]. However, the model does not take into consideration the possibility of extending the life cycle of separate vessels through their modernization.

Article [4] proposed a procedure to assess the workability index of a passenger ship. The use of this procedure makes it possible to estimate the length of time, within which a vessel will run out of its resource and it will be necessary to make decisions regarding modernization.

Paper [5] considers the main components of vessels' modernization as a way to enhance competitiveness and extend their LC. The continuation of these studies is reflected in research [6], which substantiates the need to standardize the cargo and passenger fleet, which operates on inland waterways. Modernization and standardization ensure efficiency, navigation safety, environmental safety, and the progress of the fleet in today's environment.

An important part of a vessel's modernization is to determine the scope of the required operations and to control the quality of their performance. Research [7] offers a simu-

lation model based on the "BPwin" software (developed by Computer Associates Technologies, USA), which makes it possible to assess technical efficiency and quality of planned operations at the stage of allocation of resources for vessel modernization. However, the issues of the impact of modernization on the income and expenses of a shipowner remained unresolved.

Article [8] contains an overview of innovative solutions and an analysis of their applicability on upgraded and converted cruise vessels. The proposed innovative solutions contribute to a significant improvement in the technical and economic performance of passenger ships, as well as to increase the level of cruises quality.

Study [9] presents the results of a pilot test of the system of passenger's comfort personalization inside his cabin. The system also enables a vessel owner or a cruise manager to track the condition of each cabin using sensors and a dashboard. The obtained information makes it possible to think over planning the operations on maintenance, energy saving, and detecting safety problems.

Paper [10] is based on the choice of an economically beneficial water desalination system for installation on a passenger ship.

Study [11] proposed a model of the absorption refrigeration system on board a passenger ship, the use of which would reduce annual fuel consumption and emissions accordingly.

Paper [12] examines alternative concepts for improving the energy efficiency of cruise vessels by modeling the operation of vessels equipped with different new energy generation systems. The study revealed that double-pressure steam systems, the use of low-temperature water have the greatest potential to ensure the reduction of fuel consumption and to improve the energy efficiency of cruise vessels.

Papers [8–12] contain various technical solutions to improve vessels, the introduction of which can improve the efficiency of the vessels' operation, ensuring the environmental protection, safety, and comfort of passengers.

A whole range of studies [1, 2, 5, 6, 8] points out that modernization of vessels contributes to the fleet renewal as a temporary measure, which makes it possible to increase over time the modernization of the passenger fleet with the help of shipbuilding. Thus, a shipowner will not need to invest simultaneously huge funds in the construction of a new fleet and will have time to train specialists for high-quality maintenance of new vessels.

However, it does not address the issues of distribution of the ship owner's funds among the options for vessels' modernization under conditions of limited funds. In addition, there is no clarity in the set of operations on the modernization of the passenger fleet and their utility.

That is why it seems appropriate to conduct a study on the development of the optimal strategy for the distribution of monetary funds in the modernization of passenger ships, based on the utility of certain types of modernization operations.

3. The aim and objectives of the study

The aim of this study is to develop a strategy to improve the efficiency of modernization of passenger ships by optimal distribution of the ship owner's money.

To achieve the set aim, the following tasks were set:

- to establish the composition and the content of the LC stages of the passenger ships;
- to structure the main types of operations on the modernization of passenger ships and to determine their utility;
- to create an optimal model of distribution of the ship owner's funds among the groups of operations on the passenger ship modernization.

4. The composition and content of stages in the life cycle of passenger ships

A shipping company, like any system, has its own life cycle (LC). In some ways, the human life cycle (or that of any other living organism) and that of a shipping company are similar. This is manifested in the existence of the stages of birth, development, prime, maturity, aging, and death. However, unlike human LC stages, the stages of a shipping company are not limited strictly in time. A shipping company can remain at the prime and maturity stages for many decades thanks to constant development and innovation implementation in various areas of its activity.

The activity of an SC in the passenger transport market is carried out with the help of the passenger fleet. In the constantly changing passenger market, it is important to systematically monitor the demand for passenger transportation by water in a given region and routes. If the demand for a route is constant, but a shipowner does not make a profit, it can be concluded that the vessel's LC is in decline. In this case, a shipowner needs to take a number of measures aimed at bringing the vessel in line with the requirements of the market.

For the cargo fleet, the potential to provide transportation services is determined by the market situation rather than the age and the state of a vessel. It is because consumers almost do not care about the condition and age of a vessel when buying the cargo transition [13]. However, the age and condition of a vessel play a significant role in passenger shipping, where passengers, unlike cargo, require certain conditions and comfort. This is especially true for cruise vessels.

It should be noted that a cruise vessel performs not only a tourist function but also the same technical operation as, for example, a linear one, transferring tourists between river or seaports. That is why all of the following will be true for cruise vessels as well.

Systemic analysis of the operation of passenger ships makes it possible to assume that their LC includes the following stages (Fig. 1):

1. Designing the vessel. The designing organization, based on the customer's application, which contains technical and operational requirements for a vessel, draws up a technical task for the design of a vessel, which is approved by a customer. It is followed by designing a technical proposal, based on which a sketch (pre-contract) project is developed. And in conclusion, there is a presentation of a technical project, based on which a contract will be concluded, followed by the construction of a vessel.

At the stage of designing a vessel, the designing organization takes into consideration all customer's wishes as far as possible. The wishes that cannot be fulfilled are replaced with an alternative option. All details and nodes, materials of the hull and those of interior space, the interior, location of public premises and cabins, the comfort level, fire safety systems, the number and the type of rescue equipment, swim-

ming region, and more things are taken into consideration. All technical and operational characteristics of a vessel are determined at the design stage. The project cost and economic efficiency of the vessel's operation are also calculated. The entire project is fixed in technical documentation.

2. Construction of a vessel. The costliest stage of the passenger ship LC. It includes ordering and supplying the necessary raw materials and the materials for manufacturing nodes, parts, parts of the hull, and their production. It comprises assembling hull structures, including engineering communications, installation of cabins (in cruise vessels), descent from the stump, refurbishment, interior arrangement, and more. Currently, due to technological advances, it takes 2 years to build a modern cruise liner with a passenger capacity of 6,000 people, but the cost of such a vessel is fairly high, taking into consideration its specifics; it makes up more than USD 1 billion.

3. Vessel's operation. It includes such components as commissioning, taking to balance, voyage operation: passengers' embarking or disembarking, the transition between ports with or without passengers. At the same time, passengers and the crew use internal communications, interior items, and food and water supplies. Technical operation includes ongoing and planned maintenance and repairs, as well as bunkering of a vessel.

During its operation, a vessel undergoes physical and moral aging. When a vessel is physically aging, it loses its consumer qualities and value. Its physical wear can be partially restored with the help of timely repairs and modernization.

Moral wear and tear is the result of scientific and technological advances when passenger ships cease to be up to modern techniques and technologies.

4. Vessel modernization. As a result of the operation and technological advances, periodically passenger ships need to be modernized. Since modernization usually takes place in dry docks, requires capital investment, and can lead to a significant change and renewal of a vessel, it is advisable to consider it as the LC stage of a separate vessel. In addition, during the modernization period, a vessel is not able to perform its transport operation, and the lack of modernization leads a vessel to the last LC stage – its disposal.

The main components of vessel modernization include renovation, refurbishment, modernization [14], and conversion.

Renovation refers to a set of measures aimed at modernization of the vessel's hull. At the same time, the year of construction, the original class, and the type of vessel remain unchanged. The main drawback is that the renovation concerns only the assessment of the reliability of the vessel's hull. Machinery, mechanisms, and devices of a vessel remain unchanged [1].

The purpose of the conversion of vessels is often to change their purpose. Conversion is often accompanied by a change in the main dimensions of a vessel. The implementation of such solutions results in the creation of a new vessel, different from the basic project by dimensions, purpose, seaworthiness, and technical and economic indicators [5]. There are a lot of options for the conversion of vessels:

- a barge is converted into a passenger ship;
- a linear vessel is converted into a cruise vessel;
- a cruise vessel is converted into a floating hostel for workers that implement the maintenance of a floating drilling rig, etc.

Passenger ships can also be converted not to change their purpose, but to increase passenger capacity and comfort.

Modernization involves replacing outdated interior elements with more modern versions or installing new ones. Interior items (replacement of furniture items, upholstery, etc.), vessel's power plants, machinery and devices, heating and air conditioning systems, automation and control systems, a radio navigation system, and a lot of others undergo modernization.

Conversion makes it possible to significantly extend the service life of a vessel and improve its operation safety within a reasonable time and with lower costs than those in conventional shipbuilding. Conversion involves the construction of new vessels using the elements of donor vessels. After conversion, a vessel is presented for certification by the Classification Society as a new one as of the date of presentation. Thus, after the conversion operations, a shipowner receives a virtually new vessel with a full set of documents approved by the Classification Society, and the service life of a vessel can be calculated from the date of conversion [1].

5. Disposal of a vessel. Decommissioning. Demolition of the interior and internal engineering communications. Cut of the hull of a vessel and sorting of the resulting metals. Transportation of waste to landfills and recycling plants. The practice of selling to hotels of interior items and furniture that have not failed is widely used during the disposal of a passenger ship.

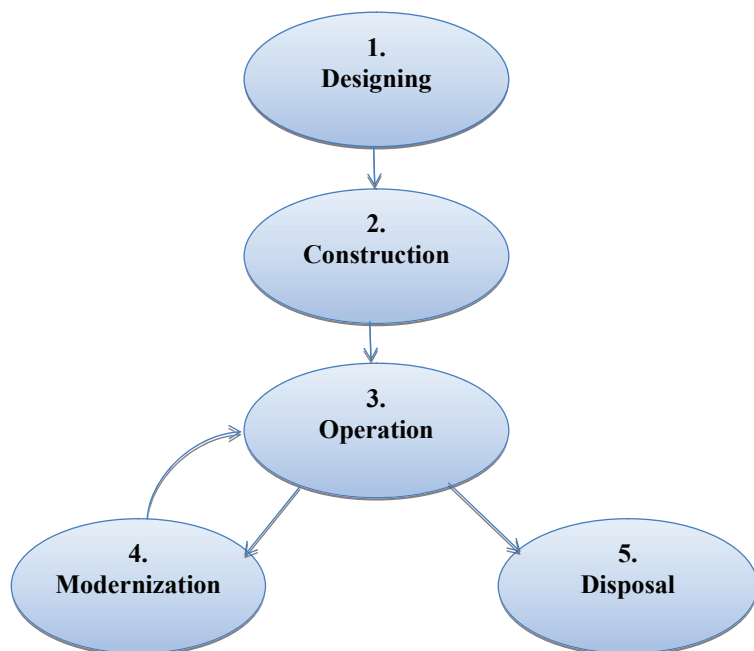


Fig 1. Stages in passenger ship LC

The criterion for the fleet operation efficiency is constant technical readiness of the assigned number of vessels and ensuring a continuous cycle of their operation for the intended purpose and at minimum costs of financial resources of ship owners [3].

As already noted, passenger ships get morally and technically obsolete during operation. This leads to a decrease in their value, an increase in operating costs, a decrease in revenue due to a decrease in demand, as well as lower seaworthiness and passenger safety.

As one can see from Fig. 1, modernization contributes to the extension of the passenger ship's LC in general. Of course, the best strategy for passenger fleet modernization is shipbuilding. However, given that the construction of a

passenger ship requires significant investments, which ship owners often do not possess, a temporary alternative to shipbuilding is the modernization of the passenger fleet.

5. The structure and usefulness of operations on the modernization of passenger ships

Most often, when the passenger fleet starts aging, ship owners carry out expensive modernization of cabins in order to increase their comfort. Comparative analysis of modernization and conversion of river cruise vessels is presented in [15]. According to study [15], modernization and conversion resulted in a significant increase in the quality of passenger's accommodation. This is due to an increase in the specific area of public premises by 63–221.5 %, depending on the type of vessel's design.

However, the ignored problems of moral obsolescence often include the engines that do not meet modern requirements of ecology, a significant number of crew members and maintenance personnel, lack of modern automation tools, etc. For example, it was required to solve the problem of modernization of the wastewater treatment system on passenger ships of the USS "Moldavia" and "Ukraine" long ago, however, it was addressed only in 2018. It happened due to the issue of

the impossibility to operate vessels on the Upper and Middle Danube because of their inconsistency with the EU environmental legislation. The cleaning system on "Moldavia" and "Ukraine" vessels used chlorine, which is prohibited in Europe.

Modernization and introduction of new technologies make it possible to ensure not only the environmental safety of passenger ships but also to reduce operating costs.

An example is the modernization of project 24 E type METEOR No. 237. The installation of a new 12-cylinder diesel with the engine power of 809 kW at 2,100 rpm produced by MAN resulted in a decrease in fuel consumption by more than 50 liters per hour and in a complete decrease in oil consumption. Savings in operating costs helped recoup the costs of modernization within several seasons.

Table 1 gives the main operations on the modernization of a passenger ship and the usefulness of these operations. It should be noted that the list of modernization operations, shown in Table 1, is not complete, and each vessel has its own list of operations implying determining their scope and costs.

Table 1 shows that there are types of operations that directly affect the profit gain through increased income or reduced operating costs. There is also a group of operations that affect indirectly through ensuring the safety of a passenger ship and the smooth operation of a vessel, as well as ensuring the comfort of passengers. Otherwise, a shipowner may suffer losses due to frequent breakdowns or even loss of a vessel, due to increased insurance payments, as well as due to reduced demand from passengers.

As a rule, on newer vessels, modernization is limited to a change of the interior, a change in the internal layout of public places, sometimes to an increase in passenger capacity due to a change in the area of public places and overhauling various technical systems. This is related to the need to attract new passengers – tourists and it a common practice on cruise vessels.

Table 1

The structure of operations on the modernization of a passenger ship and their usefulness

Structure of operations (installation from scratch/replacement for new ones/overhaul), $K_c (c=1, 2, \dots, C)$	Usefulness	
Power energy plant	Replacement for the new one	A decrease in costs due to a decrease in fuel and oil consumption. An increase in speed
	Overhaul	
Water desalination system	Installation from scratch	A decrease in costs
	Replacement for the new one	
Air conditioning system	Overhaul	Ensuring passengers' comfort A decrease in costs
	Installation from scratch	
Heating system	Replacement for the new one	Ensuring the safe and failure-free operation of a vessel (otherwise, a shipowner will not make a profit due to frequent breakdowns)
	Overhaul	
System of monitoring and control of the engine and support systems	Installation from scratch	Ensuring passengers' comfort A decrease in costs
	Replacement for the new one	
Automatic system of controlling a vessel	Overhaul	Ensuring the safe and failure-free operation of a vessel (otherwise, a shipowner will not make a profit due to frequent breakdowns)
	Installation from scratch	
Radio-navigation equipment	Replacement for the new one	Ensuring the safe and failure-free operation of a vessel (otherwise, a shipowner will not make a profit due to frequent breakdowns)
	Overhaul	
Close system of sewage and domestic wastewater	Installation from scratch	Ensuring the safe and failure-free operation of a vessel (otherwise, a shipowner will not make a profit due to frequent breakdowns)
	Replacement for the new one	
Anti-fire system	Overhaul	Ensuring the safe and failure-free operation of a vessel (otherwise, a shipowner will not make a profit due to frequent breakdowns)
	Installation from scratch	
Elements of the moving-steering complex	Replacement for the new one	Ensuring the safe and failure-free operation of a vessel (otherwise, a shipowner will not make a profit due to frequent breakdowns)
	Overhaul	
Hull renovation	1SS	Increased revenue due to an increase in: – passenger capacity; – comfort
	2SS	
	3SS	
Vessel conversion without changing the purpose	An increase in dimensionality	Profit gain
	A change in the area of public premises to increase the passenger capacity while maintaining the level of comfort	Profit gain due to enhanced comfort
	A change in the area of public premises to increase the area of cabins while maintaining the passenger capacity	Profit gain
	A change in the area of public premises in order to create additional entertainment facilities, recreation areas, and catering facilities	Profit gain
Interior	A change in the layout of public premises	Ensuring passengers' comfort (encourages demand)
	Furniture replacement	
	Replacement of soft furniture	
	Replacement of interior items	
	Installation of modern TV	
IT-infrastructure	Replacement of carpeting	Ensuring passengers' safety (increases attractiveness for passengers, promotes a demand)
	Installation from scratch	
	Replacement for the new one	
Rescue facilities	Overhaul	Ensuring passengers' safety (increases attractiveness for passengers, promotes a demand)
	Installation of additional rescue facilities	

In older vessels, in addition to cabins, various technical systems are also subject to modernization, in addition to cabins.

Each passenger ship can be considered as a system, in which its elements, such as a hull, an add-on, equipment, and

mechanisms interact. At the same time, the vessel itself is an element of a certain system, in which it is connected by the production process with other elements (enterprises and organizations).

The operation of a system in general depends on each element of a system and on the nature of the relations between them.

Consider a passenger ship as a system, to improve the efficiency of which it is necessary to carry out N groups of modernization operations. Funds in X amount are distributed among the groups of operations.

Thus, a shipowner faces the task to distribute the funds invested in the process of fleet modernization so that the total profit gain could be maximized. The algorithms of solving a similar problem, based on linear programming models, do not reflect the dynamics of the arrival of funds for certain types of modernization operations. When solving the tasks based on the principle of optimality of R. Bellman, one meets the conditions, under which the decision chosen at any step of a system change will be the best in terms of the problem in general.

6. Optimal model of distribution of the funds of a shipowner among the groups of operations on passenger ship’s modernization

State the problem in the following way. Assume that N processes of investment in the vessel’s modernization operations are numbered by the numbers 1, 2, ..., N . Each process corresponds to a utility function that expresses the dependence of the profit gain on the amount of investment in a certain totality of modernization operations. Designate the amount of money allocated for conducting i -th vessel’s modernization operations through x_i , then $g_i(x_i)$ is the increase in profits from this investment process.

It is necessary to choose the optimal distribution of funds among the options of modernization operations, providing a maximum profit gain P

$$P = \sum_{i=1}^N g_i(x_i), \tag{1}$$

where functions $g_i(x_i)$ are given. At the limiting condition

$$x_1 + x_2 + \dots + x_N = X, \quad x_i \geq 0, \tag{2}$$

where X is the total amount of monetary resources.

It is obvious that the profit gain is measured in monetary units and depends on the utility of performed operations. In turn, the utility of the modernization operations is expressed in the ability to reduce operating costs and increase revenue (for the operations that directly affect profit gain).

The dynamic distribution process implies that instead of solving one problem with a certain amount of funds and a fixed number of processes of investing in the vessel’s modernization, the family of sub-problems is solved. In each sub-task, x can take any positive values and N can take any integral values. Distribution of funds conditionally takes place in each unit of time. First, a certain amount of funds is assigned to the N -th investment process, then to the $(N-1)$ -th, and so on [16, 17].

At the same time, the number of steps N equals the number of groups of modernization operations, between which funds are distributed in the amount of X .

The state of the system at each step is characterized by the amount of monetary funds x_N , available before the given step $x_N \leq X$.

The amount of funds allocated to the i -th group of modernization operations is the control at the i -th step x_i ($i=1, 2, \dots, N$),

The utility function at the i -th step is $g_i(x)$. This is the utility of the conducted i -th group of operations at the investment of money x_i .

The condition of the transition of the function to a new state is: if at the i -th step the system is in state X and control x_N is chosen, the system will be in state $(X-x_N)$ at the next $(i-1)$ -th step.

$$W_i(X, x_N) = X - x_N. \tag{3}$$

At the last step, before investing in the last group of modernization operations, all remaining funds must be invested in the last group of operations. The profit gain is equal to the profit gain obtained as a result of the last group of modernization operations.

The optimal increase in profit gain from the distribution of money amount X among N investment processes can be expressed by a sequence of functions $\{F_N(X)\}$ as follows:

$$F_N(X) = \max_{\{x_i\}} P(x_1, x_2, \dots, x_N), \tag{4}$$

under conditions (2). At $g_1(0)=0$, the following equality is true

$$F_N(0) = 0, \quad N = 1, 2, \dots, \tag{5}$$

and

$$F_1(x) = g_1(x), \tag{6}$$

for $x \geq 0$.

As $F_{N-1}(x-x_N)$ is the optimal profit gain from the distribution of the amount of funds $x-x_N$ in $N-1$, the basic functional equation takes the following form

$$F_N(X) = \max_{0 \leq x_N \leq X} [g_N(x_N) + F_{N-1}(X - x_N)], \tag{7}$$

for $N=2, 3, \dots, x \geq 0$.

The problem will be stated as follows. As a result of the analysis of the technical and moral state of a vessel, certain necessary kinds of operation were identified and grouped into three separate groups, which will ensure:

- 1) faultless operation of the life support mechanisms of a vessel;
- 2) comfort and attractiveness for passengers;
- 3) comfort and safety.

The cost of carrying out the operations of every group, depending on their volume and the kind, was determined in the range of USD 2.5–10 million. The expected profit gain as a result of conducting the modernization operations of group 1 made up 5–20 %, of group 2 – 5–10 %, of group 3 – 7–15 % (Table 2). It was established at the preliminary stage what profit gain $g_i(x)$ each i -th group of vessel’s modernization operations will bring if the funds in the amount of x_i are invested in it (Table 3). In this case, $F_i(x)$ is the amount of profit gain during the distribution of investments in the amount of x_i among the groups of vessel’s modernization operations.

It is obvious that the cost of a complete modernization is much higher than the funds available to a shipping company. It is necessary to find such an optimal variant of distribution of investments in the modernization of a passenger ship, at which $F_i(X)$ will be maximum.

The source data $g_i(x_i)$ are given in Table 3. Tables 4–6 are to be compiled in the process of determining the values

of $F_i(x_i)$. Using the recurring equation (7), we will determine the best option.

$F_1(x_i)$ is determined from formula (5) at each step i ($i=1, 2, \dots, N$).

Table 2

The composition of the groups of vessel modernization operations

Group	Type of operation	Effect of operation execution
1	<ul style="list-style-type: none"> - Power energy plant - System of monitoring and control of the engine and support systems - Air conditioning system - Radio navigation equipment - Elements of propulsion-rudder complex - Water desalination system - Close system of sewage and domestic wastewater 	5–20 % savings of operation costs
2	<ul style="list-style-type: none"> - Interior - Hull renovation 	5–10 % increase in revenue due to the vessel load factor
3	<ul style="list-style-type: none"> - Vessel conversion without a change of purpose - Rescue facilities - Anti-fire system 	7–15 % increase in revenue due to an increase in the cost of the journey due to an increase in comfort

Table 3

The source data to solve the problem of the optimal distribution of funds among the groups of passenger ship’s modernization operations

Funds, thousands of monetary units	Group of operations		
	1	2	3
	Profit gain, thousands of monetary units		
x	$g_1(x_i)$	$g_2(x_i)$	$g_3(x_i)$
2,500	25	25	35
5,000	55	33	47
7,500	89	47	63
10,000	100	50	75

Table 4

Result of determining $F_1(x_i)$

x	$g_1(x_i)$	$F_1(x_i)$
2,500	25	25
5,000	55	55
7,500	89	89
10,000	100	100

Next, we determine $F_2(x_i)$ at each step i ($i=1, 2, \dots, N$).

Table 5

Result of determining $F_2(x_i)$

x	$F_1(x_i)$	$g_2(x_i)$	$F_2(x_i)$	$\max[g_2(x_i)+F_1(X-x_i)]$
2,500	25	25	25	$g_2(x_1)+F_1(x_0); g_2(x_0)+F_1(x_1)$
5,000	55	33	80	$g_2(x_1)+F_1(x_1)$
7,500	89	47	89	$g_2(x_0)+F_1(x_3)$
10,000	100	50	114	$g_2(x_1)+F_1(x_3)$

Explanations to Table 5:

$$F_2(2,500,000) = \max_{x_i} [g_2(x_1) + F_1(X - x_1)] = \max_{x_i} [g_2(x_1) + F_1(x_0); g_2(x_0) + F_1(x_1)], \quad i = 0, 1. \quad (8)$$

$$F_2(5,000,000) = \max_{x_i} [g_2(x_2) + F_1(X - x_2)] = \max_{x_i} [g_2(x_2) + F_1(x_0); g_2(x_0) + F_1(x_1); +F_1(x_2); g_2(x_1) + F_1(x_1)], \quad i = 0, 1, 2. \quad (9)$$

$$F_2(7,500,000) = \max_{x_i} [g_2(x_3) + F_1(X - x_3)] = \max_{x_i} [g_2(x_3) + F_1(x_0); g_2(x_0) + F_1(x_3); g_2(x_1) + F_1(x_2); g_2(x_2) + F_1(x_1)], \quad i = 0, 1, 2, 3. \quad (10)$$

$$F_2(10,000,000) = \max_{x_i} [g_2(x_4) + F_1(X - x_4)] = \max_{x_i} [g_2(x_4) + F_1(x_0); g_2(x_0) + F_1(x_4); g_2(x_1) + F_1(x_3); g_2(x_2) + F_1(x_2); g_2(x_3) + F_1(x_1)], \quad i = 0, 1, 2, 3, 4. \quad (11)$$

Then determine $F_3(x_i)$ at each step i ($i=1, 2, \dots, N$)

Table 6

Result of determining $F_3(x_i)$

x	$F_2(x_i)$	$g_3(x_i)$	$F_3(x_i)$	$\max[g_3(x_i)+F_2(X-x_i)]$
2,500	25	35	35	$g_3(x_1)+F_2(x_0)$
5,000	80	47	80	$g_3(x_0)+F_2(x_2)$
7,500	89	63	115	$g_3(x_1)+F_2(x_2)$
10,000	114	75	127	$g_3(x_2)+F_2(x_2)$

Explanations for Table 6:

$$F_3(2,500,000) = \max_{x_i} [g_3(x_1) + F_2(X - x_1)] = \max_{x_i} [g_3(x_1) + F_2(x_0); g_3(x_0) + F_2(x_1)], \quad i = 0, 1. \quad (12)$$

$$F_3(5,000,000) = \max_{x_i} [g_3(x_2) + F_2(X - x_2)] = \max_{x_i} [g_3(x_2) + F_2(x_0); g_3(x_0) + F_2(x_1); +F_2(x_2); g_3(x_1) + F_2(x_1)], \quad i = 0, 1, 2. \quad (13)$$

$$F_3(7,500,000) = \max_{x_i} [g_3(x_3) + F_2(X - x_3)] = \max_{x_i} [g_3(x_3) + F_2(x_0); g_3(x_0) + F_2(x_3); g_3(x_1) + F_2(x_2); g_3(x_2) + F_2(x_1)], \quad i = 0, 1, 2, 3. \quad (14)$$

$$F_3(10,000,000) = \max_{x_i} [g_3(x_4) + F_2(X - x_4)] = \max_{x_i} [g_3(x_4) + F_2(x_0); g_3(x_0) + F_2(x_4); g_3(x_1) + F_2(x_3); g_3(x_2) + F_2(x_2); g_3(x_3) + F_2(x_1)], \quad i = 0, 1, 2, 3, 4. \quad (15)$$

At the next step, choose the largest value from values of $F_i(x_i)$ ($i=1, 2, 3, 4$) that were already calculated. In the considered case $F_3(x_4)$ has the maximum value, therefore, distribution of all funds among three groups of vessel's modernization operations will give the highest profit gain – USD 127,000. From formula (15), determine at which step ($i=0, 1, 2, 3, 4$) $g_3(x_i)+F_2(X-x_i)$ gives the highest value. In the considered case, it is $g_3(x_2)+F_2(x_2)$, therefore, it is necessary to invest x_2 of monetary funds, that is, USD 5 million in group 3 of modernization operations. In this case, a shipowner will have the funds left that can be invested in the other two groups of vessel's modernization operations in the amount of x_4-x_2 , in other words, USD 5 million. Then, in equation (9), determine at which step ($i=0, 1, 2$) $g_2(x_i)+F_1(X-x_i)$ gives the highest value. In the considered variant, it is $g_2(x_1)+F_1(x_1)$, therefore, it is necessary to invest x_1 of monetary funds, in other words, USD 2.5 million in group 2 of the vessel's modernization operations. The rest of the ship owner's funds will be determined as $x_4-x_2-x_1$, in other words, USA 2.5 million. Evidently, it is necessary to invest USD 2.5 million in group 2 of modernization operations.

Thus, it can be concluded that in order to achieve the highest profit gain as a result of the passenger ship modernization, the SC needs to distribute the monetary funds as follows:

- to invest USD 2.5 million in group 1;
- USD 2.5 million in group 2;
- USD 5 million in group 3.

The strategy of the passenger ship's modernization by means of optimal allocation of funds to the groups of modernization operations consists of the following stages:

At the first stage, based on analysis of the technical and moral state of a passenger ship, the types, and volumes of modernization groups K_c , as well as their cost C_j are determined. In this case, it is appropriate to make a list of operations in order of their importance, from the most to the least important. It is also necessary to alternate the operations that directly and indirectly affect the profit of a shipowner. Then these operations are grouped according to the purpose, and the amount of expenditures in the group of operations must correspond to $[x_i, x_N]$, ($i=1, 2, \dots, N$).

$$\sum_{j \in J^k} C = [x_i, x_N], (i=1, 2, \dots, N), \tag{16}$$

where k is a group of operations.

At the second stage, the value of the profit gain from the passenger ship's modernization for the groups of operations is determined. The value of the profit gain ΔF is determined as follows:

$$\Delta F = F^X - F^{X-xn}, \tag{17}$$

where F^X is the profit that a vessel brings in previous state X ; F^{X-xn} is the profit that a vessel will bring in the following state $X-xn$, which began as a result of allocating the funds to execute the groups of modernization operations.

If the profit gain is negative ($\Delta F < 0$), it is not advisable to include such a vessel in the modernization plan. A vessel owner should consider the option of selling a vessel or a plan of its disposal.

At the third stage, the problem of the optimal distribution of funds among the groups of the passenger ship's modernization operations is solved.

7. Discussion of results of developing a strategy for passenger ship modernization by the optimal distribution of funds

Modernization is a separate stage of the passenger ship's LC (Fig. 1). Modernization makes it possible to upgrade the fleet and, as a result, to extend its LC. The structure of the modernization operations includes the operations, aimed at ensuring the technical order of a vessel and the comfort of passengers. At the same time, execution of the operations, depending on the type and the volume, ensure certain utility – reducing costs, increasing demand for a vessel and revenue, ensuring the safety of passengers and the environment, maintaining the class (Table 1). The kinds of modernization operations are divided into those that have a direct impact on a profit increase as a result of modernization and those that have an indirect impact. Only consolidation of operations into groups, which will contain the types of operations, both directly and indirectly affecting the profit gain as a result of their implementation, will ensure the modernization effectiveness in general.

The efficiency of modernization operations is achieved through such allocation of funds to each group of operations, which gives the largest increase in profits (1). Using the optimality principle by Bellman makes it possible to ensure the satisfaction of the condition, under which the solution was chosen at any step i will be the best in terms of the problem in general.

Formalization of the problem of distribution of funds between the groups of operations of the passenger ship's modernization will ensure its competitiveness and future operational efficiency.

It is known that modernization requires significant investment, while the ship owner's funds are often limited. Unlike previously considered studies on the fleet modernization [5, 8–12], the proposed strategy makes it possible not only to comprehensively improve the technical characteristics of a vessel but also to ensure the profit gain as a result of their implementation, thereby ensuring the modernization effectiveness.

The feature of the developed strategy is that it is ineffective in carrying out single-time restoration operations. In implementing the proposed strategy, a shipowner may face difficulty at the stage of grouping the modernization operations. Initially, it is important to properly group the operations according to the range of volume and cost, as well as their utility. If the operations directly and indirectly affecting the profit gain do not alternate when they are grouped, the following situation may arise: some groups of operations will give a significant increase in efficiency from their execution; the other will not have any effect from their execution. A formal approach may result in the funds being directed only to the types of operations that have a pronounced financial result. This may lead to a violation of the complexity (technological integrity) of the execution of the operations, which entails not only violation of conditions of the safety of vessel operation, but also an increase in its breakdown rate.

The proposed model and the algorithm for solving the problem can be also applied for the passenger fleet modernization in general. In this case, specific passenger ships are considered, and the values of X will indicate the magnitude of the funds that should be allocated to execute the operations on their modernization.

8. Conclusions

1. The composition and the content of the stages of passenger ships' have been established. It is appropriate to consider modernization as a separate stage of vessels' LC. In practice, modernization is widely used as a way to update and, as a result, to extend the vessels' LC. Depending on the age, the region of operation, and the form of operation, both the technical systems of a vessel and a cabin can be subjected to modernization. In order to increase the passenger capacity and/or comfort, various options for the conversion of passenger ships can be implemented. At the same time, it is possible that a vessel can be so worn out morally and technically that it will not bring any profit gain after modernization.

2. The content of the main types of operations on the modernization of passenger ships, as well as the usefulness of their execution, was established and revealed. The utility of modernization operations implies the following: ensuring the safety of passengers and the technical order of a vessel; saving fuel and lubricant consumption, an increase in the speed of a vessel, improved vessel comfort, an increase in passenger capacity. The direct impact on the ship owner's

profit gain is produced by modernization operations, which lead to the reduction of operation costs and contribute to increased revenues, which, as a result, leads to profit gain. The kinds of operations that provide the seaworthiness of a vessel, its safe and efficient operation have an indirect impact on the profits of a shipowner. This is due to the reliability of the fleet.

3. An optimal model for the distribution of the ship owner's funds among the groups of modernization operations was proposed. The effectiveness of this method was illustrated by the example of experimental calculation. As a result of solving the problem, it was concluded that the ship owner's profit gain will be USD 127,000 after the modernization if the funds are distributed as follows:

- to invest USD 2.5 million in the group of operations ensuring the faultless work of operation support mechanisms;
- to invest USD 2.5 million in the group of operations that enhance comfort and attractiveness for passengers;
- to invest USD 5 million in the group of operations that increase comfort and safety.

This distribution of funds among the groups of modernization operations will bring a shipowner the highest profit gain.

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