FORMULATION OBJECTIVE FUNCTION OF THE DECISION - MAKING PROBLEM IN SHIP POWER PLANT

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Abstract : *The frequent cause of ships' detentions by port authorities are abnormalities of ship power plant functioning. Each extended ship lay time in port results in waste of ship operating time thus costs rise to shipowners. This is connected with improper ship power plant management. In order to avoid this, a ship engineer should have at his disposal computer aided system supporting him in managing of ship power plant. Such a system can be worked out on condition that mathematical formula which represents the decision – making process of an engineer has been built. The present work shows the two approaches to the problem according to the situation in which the engineer is made to take certain decisions. In formulation of the two most substantial operating states of a ship like lay time in harbour and sea voyage, knapsack algorithms and task scheduling algorithms were applied. For both approaches objective function was formulated.*

1. INTRODUCTION

The analysis of Port State Control (*PCS*) reports shows that among the most frequently detained ships (due to variety of abnormalities) are vessels after several – year – long operating period (older vessels) and vessels of less capacity (less numerous E.R. crew membership). Among 10 categories into which International Maritime Organization (*IMO*) divides the reasons for ship detentions there are six when the whole or partial responsibility lies on Engine Room (*E.R.*) crew. These reasons result from non compliance, with the following conventions and codes : SOLAS – safety and fire fighting equipment, MARPOL – annex II, Load Lines – Convention, ISM Code, as well as various abnormalities observed in ship power plant like leaks on the main or auxiliary engines or disorder in ship power plant.

Estimated share of abnormalities resulting from non compliance with regulations which caused ship detentions by *PSC* amounts from 30% to 90% of all abnormalities (table 1).

Rational explanation to such abnormalities occurrences in power plant can be improper management particularly in unusual or stressful situations.

According to many experts proper management of ship power plant presents serious difficulties for decision – making engineer officers. This is caused by among others :

- increasing number of automated ship's systems,
- numerous working processes performed simultaneously,
- lack of suitable information allowing fast familiarization with systems and work planning,
- frequent change of crew membership,
- increasing requirements referring to human, ship and environment safety.

All these put ship engineer officer in stressful position and management decisions in power plant taken in such circumstances can be inappropriate or irrational causing waste of ship operating time.

Usually a team of several crew members performs multi–task work of different time range simultaneously [1] e.g.:
- fuel bunkering,
- traffic control of working operation systems,
- receiving spare parts and store supplies,
- ship ballasting,
- discharging garbage and oil wastes to special ships,
- planned prevention servicing which cannot be carried out while sailing,
- emergency repairs,
- preparing power plant for the ship to sail,
- assisting with surveys carried out on a ship by authorized surveyors e.g. *PSC*, *FSC* surveyors.

Table 1. *The estimated composition of causes stops of ships for which the machine crew answers, it was has worked out on the ground[3],[4],[5],[6]*

Conventions	Machinery & Maintenance		The causes of ships stopages for various *PSC* according to category							
			PSC K 2002		MP 2001		USCG 2001		MT 2001	
SOLAS (fire fighting appliances)	valves, fire damper	20%	36%	7%	44%	9%	12%	2%	19%	4%
	pomps	14%	36%	5%	44%	6%	12%	2%	19%	3%
SOLAS (safety in general)	electric equipment	16%	35%	6%	50%	8%	14%	2%	10%	2%
	tanks	10%	35%	4%	50%	5%	14%	1%	10%	1%
	steering machine	7%	35%	2%	50%	4%	14%	1%	10%	1%
	emerg. batteries	13%	35%	5%	50%	7%	14%	2%	10%	1%
Load lines	ventilators	20%	18%	4%	20%	4%	10%	2%	8%	2%
Propulution & Axiliary machinery	Main engine, axiliary engines, instalations, ec.	100%	15%	15%	20%	20%	9%	9%	6%	6%
MARPOL - annex II	oil separator	100%	7%	7%	26%	26%	6%	6%	10%	10%
ISM Code	maintenance	40%	15%	6%	7%	3%	15%	6%	4%	2%
				60%		91%		34%		30%
the number of stopped ships in the year				70		1600		180		360

This requires from a decision – maker i.e. ship engineer officer in charge taking rational decisions about among others : kind, range, sequence and executor of listed tasks. Such decision – making needs storing and processing huge amounts of information coming from different sources.

Processing of so much information coming from different sources can be relatively easy if *E.*R. crew of a ship is numerous and operating tasks in power plant are performed currently. The problems arise when the *E.R.* crew is not numerous and the time restrictions occur e.g.: short lay time in harbour , short passage time between harbours. These can cause wrong or inappropriate management decision – making in power plant operating thus waste of ship operating time.

To exclude such situations, a decision – maker i.e. a ship engineer should dispose of "a tool" supporting him in organization of power plant management process. The objective of such a tool would be to solve the following problem:

Knowing a set of tasks to be performed and taking into consideration all accessible resources (technical, human, time) as well as ship operating states, make a choice of such tasks which make use of resources most effectively.

In other words, the idea is to take rational decisions referring to above mentioned tasks which will be the best from operating viewpoint at a certain time and assigning them to suitable E.R. crew members to be executed.

Such "a tool" can be a computer aided system of power plant management supporting a ship engineer in making such decisions.

Nowadays a lot of ships have computer systems supporting a ship engineer in power plant management being installed or functioning. Such systems generally consist of a few modules or a few separate programmes where each of them is responsible for different area of power plant functioning. They are usually :

- diagnostic programmes (modules) provided by manufacturers of some marine machines and machineries which assess technical condition of a certain machine basing on its different operating parameters,
- service programmes (modules) providing information about forthcoming overhaulings of different kind and periodical repairs of specified machines and machineries established by manufacturers of marine machines and machineries or other institutions i.e. classification societies and the like,
- inventory programmes (modules) which control store inventory of spares, all machines, machineries and stuff used in power plant as well as facilitate ordering them.

On many ships where such systems aren't in use ship engineers by themselves prepare various tools basing on widely accessible applications i.e. excel, lotus which assist them in power plant managing .

These systems don't support decision – making but merely provide an engineer with different information needed to take management decisions in ship power plant. The engineer has to analyze accessible information by himself and on this base make appropriate decisions about planning operating tasks in ship power plant.

The objective of a computer aided system supporting the engineer in decision making i.e. the system
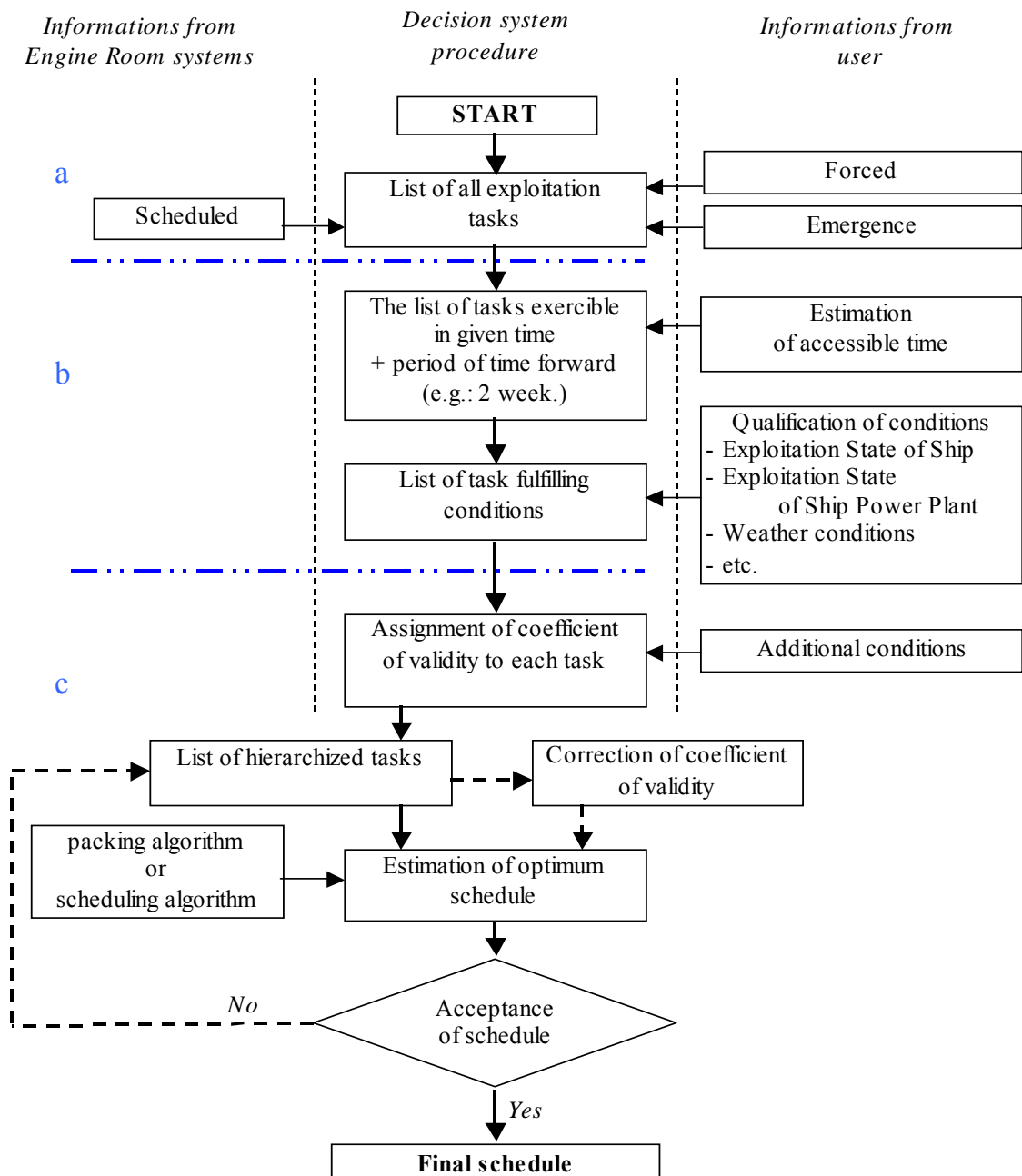
Informations from
Engine Room systems   *Decision system*
                                          procedure   *Informations from*
                                                                          user

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                          │    START     │
                          └──────┬───────┘
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a                         ┌──────▼───────┐         ┌──────────────┐
        ┌───────────┐     │ List of all  │◄────────│    Forced    │
        │ Scheduled │────►│ exploitation │         └──────────────┘
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                          ┌──────▼────────────┐    ┌──────────────┐
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                          │ exercible         │◄───│ of accessible│
b                         │ in given time     │    │     time     │
                          │ + period of time  │    └──────────────┘
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                          │ (e.g.: 2 week.)   │
                          └──────┬────────────┘
                                 │                 ┌──────────────────────────┐
                          ┌──────▼───────┐         │ Qualification of conditions│
                          │ List of task │◄────────│ - Exploitation State of Ship│
                          │  fulfilling  │         │ - Exploitation State       │
                          │  conditions  │         │      of Ship Power Plant   │
                          └──────┬───────┘         │ - Weather conditions       │
                                 │                 │ - etc.                     │
                                 │                 └──────────────────────────┘
c                         ┌──────▼─────────┐       ┌──────────────┐
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                          │ coefficient    │◄──────│  conditions  │
                          │ of validity to │       └──────────────┘
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       │  │ algorithm        │   │      schedule        │
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       │                                    │
       │         No              ┌──────────▼───────────┐
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                                 │    of schedule       │
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Fig. 1. *General decision–making algorithm in ship power plant management*

which would propose a certain solution in a particular situation would be among others :

- obtaining and gathering information which refers to realization of operating tasks in power plant or collecting such information from already being in use computer systems on board,
- analyzing any restrictions and conditions of performing appropriate operating tasks,
- making available information referring to operating tasks planning with appointing their executors.

The work [2] presents identification of a decision – making problem and its components like a set of operating tasks carried out in power plant, a set of operators who perform these tasks and a set of conditions and restrictions arising in the problem i.e. in the two first tasks presented. This work focuses on

the last task of above specified to be completed by a computer aided system supporting decision – making , on planning operating tasks.

The figure 1 shows the general procedure of solving a decision – making problem of a ship engineer where the task planning appears at stage "c".

2. OPERATING TASK PLANNING

2.1. Problem formulation

The solution to a decision – making problem which a ship engineer deals with during power plant operation is a rational schedule of tasks which are necessary to be performed in a certain operating situation.

Analysing situations when a ship engineer is likely to be made to solve a decision – making problem

described above, a few situations depending on operating condition of a ship can be distinguished.

For example, the first situation is when the ship is on a long sea voyage. In this case there are no strict time restrictions in completing either operating process in power plant or a particular operating task. Therefore the decision – making problem can be formulated as a task planning with no regard to time restrictions, so the tasks are to be planned with optimum application of accessible human and material resources also concerning realization moment of a certain task imposed by external factors such as: manufacturers of marine machines and machineries, classification societies, port control (*PSC*) and the like. In order to solve such planning problems, task scheduling algorithms are most frequently used.

Another situation is when strict time restrictions occur e.g. during ship lay time in harbour, when the exact departure time is known and the number of tasks to be completed exceeds considerably *E.R.* crew capabilities. In this situation the chief engineer has to take decision which operating tasks are to be completed in the allowed time and which tasks can be postponed for further term and who should perform particular tasks. Making inappropriate decisions at this moment can lead to failure in task realization which can result in ship detention by port control (PSC, FSC) or further break off of normal operating process of power plant e. g. black out.

Decision – making problem in this situation can be formulated as a choice of the most relevant tasks from viewpoint of power plant operating and planning them so as to make the most of the allowed time.

The following situation is when strict time restrictions occur and the best use of accessible resources is aimed at as well, which means combining the characteristic features of both specified situations. Such a formulation of a decision – making problem can be referred to the situation when the ship is being repaired in a shipyard.

In ship operating there are a lot of other situations (ship operating states), e.g. anchoring, manoeuvres, passing through a channel etc., when an engineer can be made to take decisions on task planning. However, these states make a tiny percentage of the overall operating time of a ship or they occur very seldom in her operating process, or the situation demands immediate decision – making about the method of acting (e.g. port manoeuvres) when computer aided system is unlikely to be used. Therefore the two first specified situations have been taken into account:

- lay time in harbour,
- sea voyage.

2.2. Application of knapsack algorithm in task planning in ship power plant.

The problem of task planning in ship power plant like many industrial tasks can be presented as knapsack problem which is a special case of zero–one problems of linear programming.

The standard knapsack problem [8] lies in filling the knapsack of a specified and limited volume with elements of different volume and different value in the way which enables the knapsack to be filled to the maximum with elements of the highest value. According to earlier formulation of a decision – making problem which a ship engineer deals with during ship lay time in harbour , the crew have to complete the most relevant tasks in the allowed time.

The problem of task planning i.e. assigning tasks to particular *E.R.* crew members can be considered as a multi – knapsack problem. Here knapsacks of equal volume are made of *E.R.* crew members (o_i- operators), each knapsack volume means the time allowed (e.g. lay time in port – T_S), in which the most important tasks – z_i must be completed.

A big number of operating tasks which will be used for planning results in numerous solutions satisfying all restrictions. In order to point out the optimum task planning from operating viewpoint, determination of importance indicator of each task and determination of quantity indicator *Fj* of each solution (objective function of optimization problem) are necessary.

In this task we deal with an optimization criterion, namely we have to perform the most important tasks, so the task planning should consist of task lists assigned to each operator of possibly the highest importance indicator wg_i. In addition the task planning where tasks referring to the same assembly and its sub - assemblies are grouped together should be promoted for time – saving reasons (e. g. possible time of dismantling and fitting and the like). Objective function of this problem is as follows :

$$ Fj_{\max} = \sum_{j=1}^{o} \left(\sum_{i=1}^{n} wg_i t_i x_{ij} \frac{\sum_{i=1}^{n} k_i t_i x_{ij}}{T_S} \right) \quad (1) $$

$i = 1, 2, 3, \ldots\ldots, n$ - number of tasks,
$j = 1, 2, 3, \ldots\ldots, o$ - number of operators,
$wg_i -$ indicator of task importance,
x_{ij} - 0 or 1, if task *i* is assigned to operator *j*,
k_i - number coefficient determining savings related to grouping together tasks on one assembly,
t_i - realization time of task *i*,
T_S – time allowed for realization of tasks.

$$ \sum_{i=1}^{n} t_i k_i x_{ij} \leq T_S \quad (2a) $$

$$\sum_{i=1}^{m} x_{ij} \leq 1 \qquad (2b)$$

$$k_i \begin{cases} = 1 \Rightarrow u(z_i) \neq u(z_{i-1}) \\ < 1 \Rightarrow u(z_i) = u(z_{i-1}) \end{cases} \qquad (2c)$$

$u(z_i)$ – assembly to which task i refers to,
$u(z_{i-1})$ – assembly to which task directly preceding task i in task planning refers to.

In this problem there are two primary minority restrictions, resulting from peculiar character of multi – knapsack problem [8], namely :

- a certain task can be assigned only once in planning (equation 2b), apart from the situation when it's been decided to assign a certain task to a group of operators,
- overall time for realization of tasks assigned to each operator cannot exceed time allowed T_S for their realization (equation 2a).

Additional restriction is determination of parameter k_i, which takes its value according to the assembly which the task preceding task i in planning refers to (equation 2c).

So defined objective function determines the best task planning in which the product of the importance indicators sum falling on time unit ($\sum wg_i t_i$) which will be performed by each operator and the ratio of the time realization sum of all tasks in planning to the overall time assigned for realization of these tasks ($\sum k_i t_i / T_S$) takes the highest value.

The first element of this function ensures choosing from set of tasks these which are the most important from operating viewpoint at a certain moment.

The other one forces the best possible use of the time allowed. This element can take value less or equal to 1 due to the restriction occurrence defined by equation 2a , which shows that the element ($\sum t_i x_i$) can take maximum value equal to the time allowed for realization of tasks T_S, consequently the ratio of these elements can take maximum value equal to 1 which means maximum use of time allowed. The time – saving coefficient k_i for each task plays the opposite role to penalty function applied in methods of static optimization with restrictions (in other words – a plus penalty or a reward) [9], causing decrease of the realization time in ratio to the theoretical time assigned to this task. This allows of a bigger task number to be put in planning thus increase of element respecting the sum of importance indicators and the general value of objective function.

The figure 2 presents the example of operating task planning (so called Ganit diagram [8]).

In this diagram tasks are shown in rectangular shape (coloured alternately grey – white for clarity), they are assigned to three operators o_{1-3} according to objective function (equation 1). Thus, planning comprises tasks of possibly the highest importance

indicators wg_i and at the same time of the best use of the allowed time T_S and the time left after realization of tasks anticipated in planning is minimal.

The primary element of a problem being considered is the importance indicator wg_i of each task. It determines the choice of these operating tasks which are included in the optimum planning. Though this parameter hasn't been worked out in detail by the author yet, it should include factors which are taken into account by a ship engineer when making such decisions. These factors are above all :

- technical condition of marine machines and machineries which is the most important parameter determining carrying out repairs and overhaulings of marine machines and machineries,
- time of carrying out a certain servicing imposed externally by manufacturers of marine machines and machineries, classification societies or control institutions i.e. *PSC* and the like,
- application in power plant so called devices in duplicate (a lot of marine devices in power plant are in duplicate), so one of these devices can be shut down to be serviced while the other is in operation ensuring continuous and safe realization of operating process in power plant,
- possibility of realization of a certain task in further time. Here there should be considered primarily possibility of task realization with a view to circumstances which will occur in the further considered time period i..e. next operating state of a ship, next operating state of a power plant, deterioration of technical condition of a device which the task is related to and the like.

This coefficient will be the function of these four parameters:

$$wg_i = f(St_{Ui}, Tn_i, U_i, M_i) \qquad (3)$$

St_{Ui} – technical condition of a device which the task i refers to,
Tn_i - task realization time imposed externally,
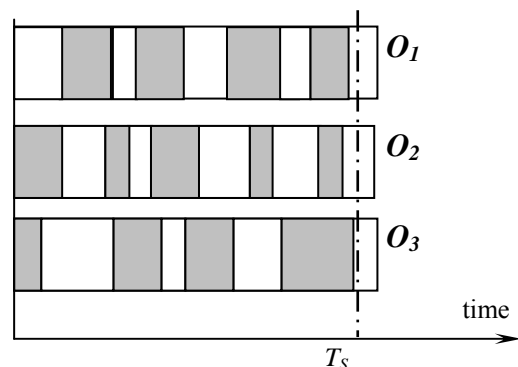U_i - coefficient respecting device duplication in ship power plant,

Fig.2. *The example of Gantt diagram for exploitation tasks planned with time limitation T_S – packing algorithm*

M_i - coefficient respecting possibility of task realization in further time.

2.3. Application of task scheduling algorithms in task planning in ship power plant.

Task scheduling algorithms seem natural for modeling a problem of operating task planning in ship power plant when a ship or engineer are in the second of the earlier described situations e.g. on ship voyage. Formulation of this problem in the earlier specified way corresponds with the general model in task scheduling theory.

Contrary to knapsack problem where the problem considered tends to resolve itself into one general model, in task scheduling problem there are a lot of models describing one specific problem which can be modified in the narrow scope. The common feature of all task scheduling models is their register method which simplifies their definition and determination of their detailed properties.

Scheduling problems is based on the two basic notions : task and resources. By task we mean to perform a sequence of activities called operations (a task may consist of one operation) where each of them requires specified resources to be engaged [7].

According to these notions in decision – making problem of a ship mechanic, we deal with tasks (operating tasks) which are to be allocated to suitable machines (here to operators of ship power plant) who work simultaneously in power plant so as to use remained resources in the optimum way, first of all the task realization time.

Frequently the sea voyage between harbours lasts a few or more days (apart from some specific vessels like ferries or other ships sailing on fixed or short routes), tasks in operating process of ship power plant can be planned regardless of time restrictions like entering a harbour because of relatively long period of time ahead.

Objective function of such a problem will be as follows :

$$Fc_{\min} = \sum_{i=1}^{n} t_i \qquad (4)$$

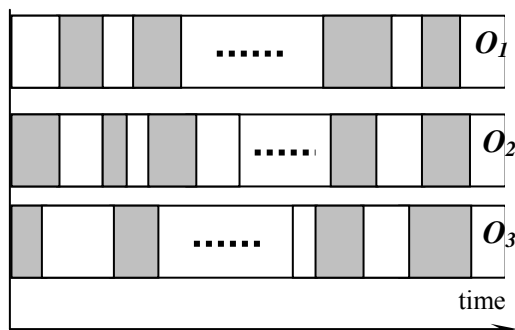In this situation the importance coefficient of each

Fig.3. *The example of Gantt diagram for exploitation tasks planned without time limitations T_S – the tasks scheduling algorithm*

task wg_i will be less meaningful as all tasks must be completed some time. Here more meaningful will be the task realization time imposed externally Tn_i , i.e. by marine machines and machineries manufacturers, classification societies and the like.

In so formulated problem there are also certain restrictions, namely :

- similarly to a case of knapsack algorithms, tasks performed on one assembly should be grouped together in one block, providing time – saving for possible dismantling and fitting of assembly components (identical with equation 2c),
- also, each task can be assigned to one operator (equation 2b),
- tasks are assigned only to available operators, in task scheduling algorithm the number of machines (operators) performing the tasks is strictly limited and cannot be changed freely. The alternation of number of operators changes the whole algorithm,
- additional constraint is necessity to avoid breaks between tasks,
- and the condition that contrary to knapsack problem all tasks assumed to be performed have to be completed.

The figure 3 shows exemplary planning of operating tasks for the situation when the ship is on sea voyage and there are no strict time restrictions, which applies task scheduling algorithm with regard to proposed objective function (equation 4).

3. RECAPITULATION

The characteristic of both approaches tempts to claim that solving entirely decision – making problem of a ship engineer is possible irrespective of the situation in which a decision is taken

(lay time in port, sea voyage and the like), when applying task scheduling algorithms with regard to suitable but different and appropriately formulated restrictions.

However knapsack algorithms seem to be more simple and better.

This approach involves fewer defined restrictions as some of the restrictions which appear in task scheduling problems (grouping tasks "no – idle ") are their natural feature.

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