Formation of optimal construction fleet composition

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Abstract. Machinery supply and its rational use in construction processes considerably determine the final product of construction organizations. Therefore, the problem of defining the type size composition of the construction fleet as one of the lowest material-intensive productions, is of a particular importance.

1. Introduction

Construction machinery is an essential technical resource in construction. Accordingly, the level of machinery availability to this type of production determines to a large extent the final product of construction organizations of different levels.

The growth of mechanical equipment and mechanization level as well as complex mechanization of construction and installation works is a pivotal direction for increasing construction engineering efficiency [1].

Taking into account the fact that modern construction sector faces a slowdown in construction fleet renovation; it has become one of the key problems to find the ways of increasing performance in the context of financial resources gap [2-11].

The construction fleet composition does not always meet the requirements of complex mechanization of construction and installation works. It lacks labour saving tools and small-size and mobile machines, allowing performing small scope of labour-intensive operations, as well as works performed in confined conditions. Building machines are frequently badly connected with each other in their main characteristics. Therefore, it is necessary to accomplish the construction fleet improvement strategy, to increase the technical level of machines, implement an intensive rather than an extensive development model.

Modern market offers various options for construction organizations: foreign and domestic machinery, after market machinery with different lifetime. It is not easy to find your way in this diversity. Therefore, different approaches permitting to choose wisely are of particular importance nowadays. Organizations must evaluate different alternative labour-saving tools, know how to make a profit and loss statement in case of using an old or new machine, calculate its rational lifetime [12-17].

As matters currently stand, the task of defining the type size composition of construction fleet is especially urgent. The current problem belongs to the class of complicated multifaceted extreme tasks. It is defined by the ability of many construction machines to perform a wide scope of operations in various conditions and almost each of them has several “competitors”. Therefore, the most profitable technique application plans and technique demand can be found only as a result of distributing operations by the minimum criteria of the reduced annual output costs.
2. Literature Review
The ideas, concepts, methodological, methodical and applied conditions of this problem have been dealt with in the works of Asaul V.V., Volkov D.P, Afanasyev V.A., Gusakov A.A., Kollegaev R.N., Vasilyeva V.M., Panibratov Y.P., Repin S.V., Grabovoi P.G., Tsai T.N., Kazakov O.B., Shreiber A.K., Mazloev V.Z., Kormakov L. F., Tuskaev T.R. and others.

3. Methodology
The task is to find such a value set of variables \( x_{ijt} \) (a need for tractor sets \( j \) for performing operations \( i \) in period \( t \)), under which the performance function has the lowest value. After selecting from \( x_{ijt} \) set the largest value \( (X_j) \), the number and composition of tractors, excavation machines, cranes and other building machinery is defined, as well as the amount and types of other aggregate working machines and devices. The suggested method of solving the task is based on economic-mathematical linear programming model. Let us assume that two types of operations «1» and «2» must be performed (for example, frozen soil ripping with a ripper-dozer). Any of them can be performed by a tractor set A or set B, but operation 1 will cost less if accomplished with set A. On the contrary, operation 2 is cheaper to be performed by set B. If both operations were performed the whole year round and equally, it would be very easy to choose the necessary tractor set and define the need for it. It is obvious that under such circumstances, set A should be planned for performing work 1, while work 2 can be done with set B. Dividing the annual work scope by the annual output of the corresponding tractor set we can find out the need for them. Such a solution will provide minimum annual operating expenses and minimum investments in technology. Now let us take a case with fluctuations in the scope of operations 1 and 2, for example, as it is shown in figure 1 when the “highs” do not concur.

If annual work scope 1 is performed by tractor set A, and annual work scope 2 is done by tractor set B, the work expenses will be minimum, but the need for both types of tractor sets will be high. The investment will also be high. Considering the fact that the “highs” do not concur, the whole or part of work 1 during the peak (second) period can be performed by set B, thus reducing drastically the need for set A, but the cost of work will increase at that, as work 1 is more expensive to be performed by set B. It is easy to notice that there can be other solutions: the peak amount of work 2 is transferred to set A, sets A and B perform operations not only in peak, but other periods (if there is a reserve); peaks exceeding the average annual scope of work are removed (shaded area in the figure) etc.

In given cases it is impossible to define the best solution in advance. It is necessary to calculate and evaluate each of them using the efficiency criterion – annual reduced expenditures on machinery purchase and operation. The amount of possible solutions significantly increases with the growth of the number of work types, peak periods, various fixed mounts used on different types of machines. The type size of a tractor set means a certain type of a machine complete with certain equipment. Table 1 shows the formation of a tractor set type size.
### Table 1. Formation of a tractor set nominal size

| Tractor nominal size | Ripper and bulldozer equipment model | The set nominal size |
|----------------------|-------------------------------------|---------------------|
| T-130                | DP-5S                               | T-130 + DP-5S       |
|                      | (D-515S)                            | T-130 + (D-515S)    |
|                      | DP-26S                              | T-130 + DP-26S      |
|                      | (DZ - 117)                          | T-130 + (DZ -117)   |
| T-180                | DP-22S                              | T-180 + DP-22S      |
|                      | (DZ – 35S)                          | T-180 +(DZ– 35S)    |
|                      | DP - 7S                             | T-180 + DP-7S       |
|                      | DZ -121                             | T180 +(D- 576S)     |

As can be seen from table, 8 type sizes of tractor sets for frozen soil ripping were formed out of two type sizes of tractors and their equipment.

On account of high dimension, the task of selecting the construction fleet composition cannot be solved by direct enumeration of possibilities. The best solution should be searched, based on logical prerequisites resulting from organizational-economic contents of the task, excluding the knowingly inefficient options. In other words, a method should be used, allowing significantly restricting the search area, but ensuring a good result at that.

In view of this, the following general scheme of solving the task seems appropriate.

1. The demand for tractor sets is calculated on condition that every operation will be completely performed by the most efficient set of them. Efficiency is estimated by the value of the work self-cost. This will be the first (basic) work and fleet composition plan. The number of certain type tractors and equipment is defined by the demand for them during the most intense week or decade. The amount of reduced annual costs is calculated according to this.

2. The work and fleet composition plan is determined on condition that tractor sets of one size type vacant every ten days do the work which according to the first (basic) plan is supposed to be done by other sets. Besides, the replacing sets must accomplish as much work as possible, thus releasing a maximum of “replaced” sets. Each of the size types performs this “replacing” function alternately. Thus, several variants of work plans and construction fleets will be produced. Their number will be equal to the amount of the sets size types plus one (the basic work and fleet composition plan).

3. The annual reduced costs are determined for every fleet composition and the most efficient is chosen among them.

4. The same selection procedure for the fleet construction is repeated when the replacing size type does not take the maximum amount of work of other sets, but only the amounts providing their equal load during the year. This calculation is also applicable on condition that the replacing type size removes only the peaks of the works exceeding the average decade amount. Such an extension of the search area ensures that the best possible variant of a fleet composition and its annual work plan will be found.

Let us study the procedure for calculating an economically efficient fleet composition reflecting the above suggestions at the example of the following specifications:

- T – amount of periods per year;
- t - number of the period (t = 1,2,…, T);
- I – amount of operation types;
- i - number of operation type (i = 1,2,…, I);
- J – amount of tractor set type sizes;
- j – number of the tractor set type size (j = 1,2,…J);
- j* - number of replacing tractor set type size ;
- m – number of priority in transferring the work from replaced to replacing tractor set type size (m = 1,2,…, M);
Qₜ – average daily work amount i in period t;

$Q^{(k)}_{ijt}$ – average daily work amount i performed by set j in period t according to plan k;

$Q^{(m)}_{ijt}$ – average daily work amount i, transferred from set j to set $j^*$ in period t in phase m;

$w_{ij}$ – performance of set j at work i in period t;

$s_{ij}$ – self cost of work i performed by set j in period t;

$M_{ij}$ – demand for sets j to perform work i in period t;

$M_{jt}$ – general demand for sets j in period t;

$M_{j(t)}^{(mp)}$ – amount of vacant sets j in period t;

$M_{j(t)}^{(mp)}$ – amount of remaining vacant sets in t-period after transferring to them shipments of m priority;

$s_{ij}^{(k)}$ – direct costs of the fleet service in work according to plan k, rbl. per year;

$s_{ij}^{(k)}$ – overhead costs in work according to plan k, rbl. per year;

$S_{pf}$ – cost of liabilities of production facilities per one tractor set, rbl. per year;

$r_{njp}$ – yearly amount of overhead costs per one set j, rbl. per year;

$\varphi_{m}$, $\varphi_{pf}$ – coefficients considering the influence of the enterprise size on the amount of overhead costs and liabilities of the main production facilities;

$\alpha_{mit}$ – coefficient of using calendar time with respect to meteorological conditions performing work i in period t;

$D_{ni}$ – number of calendar days in period t;

$Y_{ij}^{(j*)}$ – losses on replacing sets j by sets $j^*$ at work i in period t;

$C_{bij}$ – balance price of set j;

$K^{(k)}$ – capital investments in construction fleet when using in work according to plan k;

$E_n$ – regulatory coefficient of the investments efficiency;

$T_{nit}$ – working day duration performing work I in period t, hour.

4. Results

4.1 Preparing initial data (introducing invariables) (Table 2-5).

| Type of work | Period |  |  | Total |
|--------------|--------|---|---|-------|
|              | 1      | 2 | 3 | 4     |       |
| 1            | 1000   | 1000 | 3000 | 1000 | 6000 |
| 2            | 2000   | 1000 | 3000 | 1000 | 7000 |
| 3            | 2000   | 1500 | 2000 | 5000 | 10500|
| 4            | 2000   | 2500 | 1000 | 1000 | 6500 |
| Total        | 7000   | 6000 | 9000 | 8000 | 30000|

| Type size (composition) | Criteria |
|-------------------------|----------|
|                         | $C_b$    | $R_{ap}$ | $S_{pf}$ |
| A (T-130 + DP-5S)       | 1200000  | 154400   | 228300   |
| B (T-180 + DP-22S)      | 1300000  | 154400   | 228300   |
| C(DAT-250+DZ121)        | 1500000  | 182800   | 270320   |
**Table 4.** Formation of the matrix of criteria depending on the period and type of work.

| Type of work | Period | 1 | 2 | 3 | 4 |
|--------------|--------|---|---|---|---|
|              | $T_{\text{int}}$ | $a_{\text{int}}$ | $T_{\text{int}}$ | $a_{\text{int}}$ | $T_{\text{int}}$ | $a_{\text{int}}$ |
| 1            | 8      | 1  | 8  | 1  | 8  | 1  |
| 2            | 8      | 1  | 8  | 1  | 8  | 1  |
| 3            | 8      | 1  | 8  | 1  | 8  | 1  |
| 4            | 8      | 1  | 8  | 1  | 8  | 1  |

**Table 5.** Formation of the invariables matrix.

| Invariable | Value | Invariable | Value |
|------------|-------|------------|-------|
| $T_{\text{int}}$ | 4 | $D_{\text{c}}$ | 10 |
| $E_{n}$ | 0.2 | $\phi_{nr}$ | 1 |
| $\phi_{pf}$ | 1 | |

4.2 Calculating the first (basic) plan of operating the construction fleet.

The plan of operating the construction fleet is the allocation of work types according to type sizes in every period. The basic plan is projected to allow the most efficient set in the given work type to perform its total work scope (Table 6).

**Table 6.** Calculating and completing the $w_{ij}$ and $s_{ij}$ values matrix. $w_{ij}$ δ $s_{ij}$.

| Type of work | Type size of the tractor set |
|--------------|-----------------------------|
|              | A (T-130 + DP-5S) | B (T-180 + DP-22S) | C (DAT-250+ DZ121) |
|              | $w$ | $s$ | $w$ | $s$ | $w$ | $s$ |
| 1            | 8.8 | 754 | 7.09 | 1004 | 6.6 | 1103 |
| 2            | 10.3 | 648 | 8.18 | 870 | 7.7 | 945 |
| 3            | 15.48 | 443 | 12.3 | 578 | 11.55 | 633 |
| 4            | 9.58 | 693 | 7.6 | 936 | 7.15 | 1018 |

According to the results of this solution it was concluded that the tractor set A is the most preferable for all the variants. But to make the task more complicated and explain in detail the algorithm of its solution we will alter the data results of matrix 2.1. and suggest 2.1* matrix for further solution (Table 7).

**Table 7.** the data results of matrix 2.1. and suggest 2.1*

| Type of work | Tractor set type size |
|--------------|-----------------------|
|              | A (T-130 + DP-5S) | B (T-180 + DP-22S) | C (DAT-250+ DZ121) |
|              | $w$ | $s$ | $w$ | $s$ | $w$ | $s$ |
| 1            | 8.84 | 754 | 7.09 | 1004 | 6.6 | 740 |
| 2            | 10.3 | 648 | 8.18 | 630 | 7.7 | 945 |
| 3            | 15.48 | 443 | 12.3 | 578 | 11.55 | 633 |
| 4            | 9.58 | 693 | 7.6 | 936 | 7.15 | 1011 |

Selecting the most efficient unit for every type of work.
The most efficient set for the given type of work is selected by comparing values \( s_{ij} \) in matrix 2.1*. In the given example for the first type of work set C is selected, for the second type – set B, for the third and fourth types – set A is chosen (Table 8-9).

**Table 8.** Developing the first plan of construction fleet operation: the whole work-scope is performed by the most efficient sets.

| Type of work | Period and type size of the set |
|--------------|---------------------------------|
|              | 1     | 2     | 3     | 4     |
| A            | 1000  | 1000  | 3000  | 1000  |
| B            | 2000  | 1000  | 3000  | 1000  |
| C            | 2000  | 1500  | 2000  | 5000  |
| A            | 2000  | 2500  | 1000  | 1000  |
| B            | 2000  | 2500  | 1000  | 1000  |
| C            | 2000  | 2500  | 1000  | 1000  |
| Total        | 4000  | 2000  | 1000  | 4000  | 1000  | 1000  | 4000  | 1000  | 1000  | 3000  | 3000  | 3000  | 6000  | 1000  | 1000  |

4.3 Determining the construction fleet composition

Demand for sets \( j \) to perform work \( i \) in period \( t \) is calculated as follows:

\[
M_{ijt} = \frac{Q_{ijt}}{D_t \cdot a_{it} \cdot x_{ijt}}
\]

Total demand for units \( j \) in period \( t \) is calculated as follows:

\[
M_{jt} = \sum_i M_{ijt}
\]

**Table 9.** Formation of the matrix of demand for tractor sets (\( M_{ijt} \) values matrix).

| Type of work | Period and type size of units |
|--------------|--------------------------------|
|              | 1     | 2     | 3     | 4     |
| A            | 15.5  | 15.5  | 45.5  | 15.5  |
| B            | 24.4  | 12.2  | 36.6  | 12.2  |
| C            | 12.91 | 9.68  | 12.91 | 32.3  |
| A            | 20.87 | 26.09 | 10.4  | 10.4  |
| B            | 33.78 | 24.4  | 15.5  | 35.77 | 12.2  | 15.5  | 23.31 | 36.6  | 45.5  | 42.7  | 12.2  | 15.5  |

Determining the first (basic) construction fleet composition. It is determined by selecting maximum \( M_{ijt} \) values from Table 7.

In our example the basic construction fleet composition is the following:

Type size A – 42.7 sets (4- period);
Type size B - 36.6 sets (3-period);
Type size C - 45.5 sets (3-period).
In total 124.8 tractor sets

4.4 Calculating reduced costs according to the first operation plan and first construction fleet composition.

Direct costs of the fleet service are calculated by the following formula:

\[ S_{p}^{(k=1)} = \sum_{i,t} S_{ijt} Q_{ijt} \]

\[ S_{p} = 740 \cdot 6000 + 630 \cdot 7000 + 443 \cdot 10500 + 693 \cdot 6500 = 17966 \text{ thousand rubles.} \]

Values \( S_{ijt} \) and \( Q_{ijt} \) come from matrices 2.3 and 2.1*.

Overhead costs are calculated by the following formula:

\[ S_{nr}^{(k=1)} = \sum M_{j}^{(k=1)} r_{nr} \varphi_{nr} \]

\[ S_{nr} = 42.7 \cdot 154400 + 36.6 \cdot 154400 + 45.5 \cdot 182800 = 20497 \text{ thousand rubles.} \]

Full costs of the fleet service are calculated by the following formula:

\[ S_{a}^{(k=1)} = S_{p}^{(k=1)} + S_{nr}^{(k=1)} = 17966 + 20497 = 38463 \text{ Thousand rubles per year} \]

Calculated required investments:

\[ K^{(k=1)} = \sum M_{j}^{(k=1)} (C_{j} + S_{pf} \cdot \varphi_{pf}) \]

\[ K^{(k=1)} = 42.7 \cdot (1200000 + 228300 \cdot 1) + 36.6 \cdot (1300000 + 228300 \cdot 1) + 45.5 \cdot (1500000 + 270320) = 210283 \text{ thousand rubles.} \]

Calculating annual reduced costs:

\[ R^{(k=1)} = S_{a}^{(k=1)} + E_{a} \cdot K^{(k=1)} \]

\[ R^{(k=1)} = 38463 + 0.2 \cdot 210283 = 80519 \text{ thousand rubles per year} \]

4.5 Preparing data for calculating the second and subsequent plans of operating the construction fleet and its composition.

Selecting tractor set \( j^* \) from the type sizes comprising the first fleet composition, which will replace the sets of other type sizes. The replacing set is selected randomly, the number of replacement variants is equal to the number of type sizes in the first composition of the construction fleet. After calculating the second plan and the second fleet composition, we proceed to calculating the third and subsequent variants. We remind that the number of the fleet composition variants shall be equal to the number of tractor set type sizes from the first (basic) composition.

5. Conclusion

The most efficient tractor set composition is determined by comparing the reduced costs in each calculated variant.
The suggested algorithm of searching the most preferable variant can be used as a basis for a computer program for solving the problem. Simulation modeling is the most advantageous with regard to the task as it allows a dialogue between the designer and the machine in real time scale.

**Recommendations**

Simulation modeling is recommended to solve the given task. Science often faces with difficulties in conducting detailed experiments and calculations due to lack of accurate information. Therefore modeling is a powerful tool for studying objects [18-20]. Modeling process involves feeding into computer various values of certain parameters, for instance, work completion time and watch the changes of the parameters in question, for example, the demand for different tractor or excavator sets type sizes. Simulation modeling is in fact an experiment conducted in virtual rather than real conditions. In this case there is an opportunity for multivariate design, creating problems and watching the solutions on-line. This reduces significantly the time spent of the most preferable solution search.

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