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# Digitalization of planning for low-rise development of rural areas

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**Abstract.** The article is devoted to the consideration of the current problem of low-rise development of settlements in rural areas. The presence of federal and regional legislative initiatives at the strategic level of planning is noted. The purpose of the study is related to the development of methods and algorithms for the current planning of low-rise buildings. The stated task is considered as a multi-project planning problem. The problem was formulated and formalized using scheduling schemes and priority rules. For numerical experimentation, a model of a multi-project planning program and a test task were developed, including 27 projects of various buildings with household buildings. The task contains 504 requests for the implementation of project work, as well as the work requirements for workers of various specialties, construction mechanisms and funding levels. The developed program layout, in addition to carrying out calculations using the presented algorithms, visualizes the results of numerical experimentation in the form of Gantt charts and resource consumption diagrams. The performance of the developed methods and algorithms has been confirmed. Conclusions and discussion of the study results are presented.

## 1 Introduction

At the strategic level, the basis of state agricultural policy is the formation of a model for sustainable and effective development of agriculture and rural areas in accordance with the Federal Law “On the Development of Agriculture” dated December 29, 2006 No. 264-FZ (as amended on July 20, 2018). In 2019, the Russian government adopted the program “Comprehensive Development of Rural Territories” for the period up to 2025 inclusive, developed by the Ministry of Agriculture. The program provides for the implementation of measures aimed at increasing the level of employment of the rural population and creating a comfortable environment for rural residents. Creating a comfortable environment implies the

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development of water supply and sanitation systems, communications and telecommunications, and an increase in the level of gasification; creating accessibility to social services in the field of education and healthcare, as well as improving the quality of road infrastructure. It is also planned to provide rural residents with modern housing. One of the most effective ways to solve the housing problem in rural areas is low-rise housing construction with a height of up to 4 floors [1]. Domestic and foreign experience [2, 3] confirms the feasibility of this approach.

The above-mentioned documents and regional programs developed in their development form a strategic level of planning for low-rise development of rural areas. The results of regional programs can be judged, for example, from publications [4, 5].

Current planning of low-rise buildings refers to the tasks of multi-project planning, for which centralized planning is the most suitable [6]. The most significant factor in the centralization of planning is that all information about the projects of buildings under construction is known before the start of construction, and during planning, interrelated problems are solved - the formation of a calendar schedule, that is, a schedule for the implementation of all project work, and the distribution of resources. Decentralized multi-project planning will not be considered in this study due to its complexity.

Multi-project planning schedules are schedules of hierarchical or network work structures. Projects can be technologically independent, but combined in terms of consumed resources. To describe the complex of works of the project, it is necessary to have a description of each work. The complexity (duration) of work is measured in planning cycles. The resource requirements of individual jobs are measured in conventional units or real values per planning cycle. The work in each project is linked by precedence/follower relationships. It is also assumed that the required resources are homogeneous.

Multi-project planning (RCMPSP - resource-constrained multi-project scheduling problem) solves interrelated problems - the distribution of project implementation over time (formation of a calendar schedule) and the distribution of resources.

The task of generating a schedule in a system with limited resources is associated with determining the start times for the execution of all actions or their sets in the schedule interval. For multi-project planning, it is necessary to consistently solve the following problems:

1. aggregation of project requests - determining the relative initial execution times of each work within the project schedule interval. The graphical result of aggregation is the representation of the project as a set of rectangles. Each rectangle represents the work of the project and has the dimension “work duration” X “cycle resource requirement”. A consequence of the last fact is the difference in project aggregations for different resources. The aggregation process is presented in more detail in [7];

2. formation of a multi-project planning schedule - determination of the relative initial execution times of project aggregations within a specified or defined schedule interval.

Each problem is solved on the basis of the RACP model (RACP - resource availability cost problem - the task of minimizing the cost of available resources), within the framework of the accepted approach [8]. For this study, we will assume that the aggregations of all projects are known and further material in the article will be related to the solution of the second problem. Differences in project aggregations for different resources determine the multi-criteria nature of the planning problem. In this regard, most researchers recognize the NP-hardness of the multi-project planning problem and, as a consequence, the need to find heuristics that reduce the order of exhaustive search operations. The basis of heuristic approaches is the use of schedule generation schemes (SGS - schedule generation scheme) and priority rules (PR - priority rules) [9 - 12]. The priorities in this context are the criteria for determining the order of implementation (inclusion in the calendar schedule) of projects competing in terms of resources. The criteria are formed from scalar values of various project characteristics, including allocated and required resources. Priority rules are understood as certain sequences of techniques and methods for determining the order of inclusion in the calendar schedule of projects competing in terms of resources.

The purpose of the article is to present the developed methods and algorithms for generating a calendar schedule for an arbitrary number of project aggregations in a system with limited homogeneous resources.

## 2 Statement and formalization of multi-project planning tasks

To generate a calendar schedule for multi-project planning, two sequentially applied schemes for generating schedules are proposed. $SGS_1$ – scheme for generating the initial calendar schedule; $SGS_2$ - schedule optimization scheme.

Let us introduce the notation necessary in what follows.

Initial data:

$P = \{\ p_i, \quad i = \overline{1, I}\}$ - many multi-project projects;

$E_i = \{\ e_{j,i}, \quad j = \overline{1, ne_i}, \quad i = \overline{1, I}\}$ - set of projects $p_i$ (j =1 – source, j = $ne_i$ – sink);

$K = \{\ k_m, \quad m = \overline{1, u}\}$ - many types of renewable resources;

$R_{m,i}, \quad m = \overline{1, u}, \quad i = \overline{1, I}$ - the amount of resource type $k_m$ allocated at each planning cycle to project $p_i$ during its execution;

$r_{m,j,i}, \quad m = \overline{1, u}, \quad j = \overline{1, ne_i}, \quad i = \overline{1, I}$ - the amount of resource type $k_m$ required by work $e_{j,i}$ of project W during its execution at the j-th planning cycle;

$d_{j,i}, \quad j = \overline{1, ne_i}, \quad i = \overline{1, I}$ - duration (labor intensity) of performing work $e_{j,i}$ of project $p_i$;

$Int$ - schedule interval – the duration of the calendar schedule in planning cycles.

Initial calculation data:

$np_i, \quad i = \overline{1, I}$- number of paths in the network graph of project $p_i$;

$PT_i = \{pt_{j,i}, \quad j = \overline{1, np_i}, \quad i = \overline{1, I}\}$ - set of paths in the network graph of project $p_i$;

$Cp_i, \quad i = \overline{1, I}$- critical path of the project $p_i$, planning steps;

$nep_{j,i}, \quad j = \overline{1, ne_I}, \quad I = \overline{1, I}$ - the number of works on path $p_{i,j}$ of the network graph of project $p_i$;

$PE_{p,i} = \{\ e_{p,i}, \quad p = \overline{1, nep_{j,i}}, \quad i = \overline{1, I}\}, \quad PE_{i,p} \in E_i$ - set of work paths $pt_{j,i}$ of the network graph of project $p_i$;

$D_i$- duration (labor intensity) of project execution $p_i$ in planning cycles. The proposed solution adopted $D_i = Cp_i, \quad i = \overline{1, I}$;

Variables:

$ni, \quad ni = \overline{1, I}$- number of: projects included in the initial schedule; optimized (rearranged) projects in the calendar schedule;

$nr, \quad nr = \overline{1, I}$ - number of: projects not included in the initial schedule; unoptimized projects in the calendar schedule;

$R\,max_m, \quad m = \overline{1, u}$ - the maximum value of clock consumption of a resource of type $k_m$ in the calendar schedule;

$TI_i$- the initial planning step for the implementation of project $p_i$ in the calendar schedule;

$TF_i = TI_i + D_i$ - the final tact of planning project $p_i$ in the calendar schedule;

$rp_{m,j,i}, \quad m = \overline{1, u}, \quad j = \overline{TI_i, TF_i}, \quad i = \overline{1, I}$ - the amount of resource type $k_m$ consumed by project $p_i$ at the j-th tick of the schedule interval;

$RS_{m,j}, \quad m = \overline{1, u}, \quad j = \overline{0, Int - 1}$ - the amount of resource type $k_m$ consumed by the calendar schedule at the j-th tick of the schedule interval;

$RM_m = \frac{\sum_{i=1}^{I}\sum_{j=1}^{ne_i} r_{m,j,i} \times d_{j,i}}{Int}, \quad m = \overline{1,u}, \quad j = \overline{TI_i, TF_i}, \quad i = \overline{1,I}$ - the average amount of resource type $k_m$ consumed by schedule projects at each tick of the schedule interval;

$RP_{m,j,i}, \quad m = \overline{1,u}, \quad j = \overline{TI_i, TF_i}, \quad i = \overline{1,nr}$ - assessment of the uniformity of the j-th cycle of project $p_i$ according to resource type $k_m$;

$\sigma_m = \sqrt{\frac{1}{Int}\sum_{j=0}^{Int-1}\left(RM_m - RS_{m,j}\right)^2}, \quad m = \overline{1,u}$ - standard deviation of resource consumption of type $k_m$ from the average value in the schedule interval.

The problem of forming an initial calendar schedule is solved by step-by-step selection of the next project and the formation of a schedule $S = \{\ TI_i, \quad i = \overline{1,\ ni}\ \}$, which minimizes the vector of maximum values of resource consumption in the schedule interval

$$min(R\,max_1, R\,max_2,\ \dots\ ,\ R\,max_u \quad ), \tag{1}$$

subject to mandatory restrictions

$$\forall i\ TI_i \geq 0, \quad i = \overline{1,\ ni}\ ; \forall i\ TF_i \leq Int, \quad i = \overline{1,ni} \tag{2}$$

The objective function (1) ensures the minimization of the upper limit of deviations, which is sufficient to form the initial schedule when including the next project in the schedule. The objective function is associated with the need for multi-criteria ranking of the resulting vectors (1). The formation of the initial calendar schedule ends with the exhaustion of the list of projects not included in the schedule (nr = 0). Constraint inequalities (2) reflect the unconditionality of projects being within the schedule interval.

An assessment of the workload $c_{j,m,i}$ of work $e_{j,i}$ not included in the calendar project $p_i$ at the next step in the formation of the initial calendar schedule is determined by the volume of resources required during the period of work execution

$$c_{j,m,i} = r_{j,m,i} * d_{j,i}, \quad j = \overline{1,ne_i}, \quad m = \overline{1,u} \quad i = \overline{1,nr} \tag{3}$$

The greater the value of the estimate (3), the more the corresponding work $e_{j,i}$ of project $p_i$ is loaded on a resource of type $k_m$. The estimates (3) form a set of vectors (workload criteria) of work at the next step in the formation of the initial calendar schedule

$$\{\ \left(c_{j,m,i}, \quad j = \overline{1,ne_i}, \quad m = \overline{1,u}, \quad i = \overline{1,nr}\right)\ \} \tag{4}$$

Inverse multicriteria ranking of vectors (4) generates a set of ranks

$$\{\ rank1_{j,i}, \quad j = \overline{1,ne_i}, \quad i = \overline{1,nr}\} \tag{5}$$

Job ranks (5) form a set of vectors (load criteria) of paths in project network graphs

$$\left\{\ \left(rank1_{i,1},\ rank1_{i,2},\ .\ .\ .\ ,\ rank1_{i,nep_{i,j}}\right)\ , \quad j = \overline{1,\ ne_i}, \quad i = \overline{1,nr}\right\} \tag{6}$$

Inverse multicriteria ranking of vectors (6) generates a set of ranks of criteria for congestion of paths in project network graphs

$$\{\ rank2_{j,i}, \quad j = \overline{1,np_i}, \quad i = \overline{1,nr}\} \tag{7}$$

The ranks of vectors (7) form a set of vectors (workload criteria) of projects

$$\{\ RP_i\ = \left(rank2_{i,1},\ rank2_{i,2},\ .\ .\ .\ ,\ rank2_{i,np_i}\right)\ , \quad i = \overline{1,nr}\} \tag{8}$$

The project with the highest rank, obtained by direct multicriteria ranking of vectors (8), is the busiest with the accepted estimates and load criteria. He becomes another candidate $p_{ni+1}$ for inclusion in the initial calendar schedule.

To determine the initial turn-on time $TI_{ni+1}$, project $p_{ni+1}$ moves sequentially, one clock cycle at a time, taking into account restrictions (2) within the schedule interval *Int*, forming a set of vectors:

$$\left\{\ \left(R\,max_{1,j},\ R\,max_{2,j},\ \dots\ ,\ R\,max_{u,j} \quad \right)\ , \quad j = \overline{0,\ (Int - Cp_{ni+1} - 1)}\right\} \tag{9}$$

Direct multicriteria ranking of vectors (9) determines the dominant vector, the index j of which determines the desired initial time for inclusion of project $p_{ni+1}$ in the initial calendar schedule $TI_{ni+1}$. If $nr > 0$, then proceed to the next step in the formation of the initial calendar schedule.

The task of optimizing the initial calendar schedule consists of changing the initial schedule to form a schedule $S = \{\ TI_i, i = \overline{1,\ ni}\ \}$ that minimizes the vector of standard deviations of resource consumption $\left(\sigma_m,\quad m = \overline{1,u}\right)$ from the average values in the schedule interval

$$min(\sigma_1,\ \sigma_2,\ \dots\ ,\ \sigma_u) \tag{10}$$

subject to mandatory restrictions (2).

Objective function (10), being an integral estimate of the calendar schedule, minimizes all deviations. The objective function is associated with the need for multicriteria ranking of vectors obtained on its basis (10). The completion of the optimization process of the initial schedule is determined by the adopted action strategy.

An assessment of the uniformity of the j-th cycle of project $p_i$ with respect to resource $k_m$ at the next step of optimization of the initial schedule is determined by the following expression

$$RP_{m,j,i} = \frac{rp_{m,j,i} * RS_{m,j}}{RM_m * RM_m},\quad m = \overline{1,u},\quad j = \overline{TI_i, TF_i},\quad i = \overline{1,I} \tag{11}$$

The values of clock uniformity estimates are in the interval [0, 1]. The greater the value of the estimate (11), the more uneven the corresponding project is at a given tick of the schedule interval for a given resource. Project uniformity estimates (11) form u sets of vectors (uniformity criteria) of projects for each resource.

$$PR_m = \left\{\ \left(RP_{m,j,i},\quad j = \overline{1, ne_i}\right),\quad i = \overline{1,I}\right\},\quad m = \overline{1,u} \tag{12}$$

Direct multicriteria ranking of vectors (12) of schedule projects generates sets of ranks of project vectors for each resource

$$Rank3_m = \left\{\ rank3_{m,i},\quad i = \overline{1,I}\right\},\quad m = \overline{1,u} \tag{13}$$

The ranks of vectors (13) form a set of vectors (uniformity criteria) of non-optimized projects

$$\left\{RP_i = (rank3_{i,1}, rank3_{i,2}, \dots, rank_{i,u}), i = \overline{1,nr}\right\} \tag{14}$$

The highest-ranking project, obtained by direct multicriteria ranking of vectors (14), is the most uneven among the non-optimized ones with the accepted estimates and uniformity criteria. He becomes the next candidate $p_{ni+1}$ for a reshuffle in the calendar schedule.

To determine the initial time $TI_{ni+1}$ of the permutation, the project $p_{ni+1}$ is moved sequentially, one clock cycle at a time, taking into account restrictions (2) within the schedule interval *Int*, forming a set of vectors:

$$\left\{\ \left(\sigma_{1,j},\quad \sigma_{2,j},\ \dots\ ,\ \sigma_{u,j}\right),\quad j = \overline{0, Int-1}\right\} \tag{15}$$

Direct multicriteria ranking of vectors (15) determines the dominant vector, the index j of which determines the initial time $TI_{ni+1} = j$ for rearranging project $p_{ni+1}$ in the schedule. If $nr > 0$, then go to the next optimization step.

Expressions (1) – (9) represent the scheme for generating the initial calendar schedule $SGS_1$. Expressions (10) – (15) represent the optimization scheme for the initial $SGS_2$ schedule.

Each $SGS_1$ cycle uses two interrelated priority rules $PR_{11}$ and $PR_{12}$. Rule $PR_{11}$ is associated with the selection of the most loaded project in terms of required resources among projects not included in the initial schedule. The strategy of rule $PR_{11}$ is determined by working with expressions (3-8). For the project selected by rule $PR_{11}$ in rule $PR_{12}$, working with expression (9) determines the start time of execution in the initial calendar schedule, ensuring the greatest uniformity of resource consumption.

Each $SGS_2$ cycle also uses two interrelated priority rules $PR_{21}$ and $PR_{22}$. The strategy of rule $PR_{11}$ is determined by working with expressions (11-14) and is associated with the selection of the most uneven resource consumption in the project schedule. For the project selected by rule $PR_{21}$, in rule $PR_{22}$, by working with expression (15), the start time of execution in the schedule interval is determined that at least does not worsen the integral assessment of uniformity (uniformity criterion) of the entire schedule.

## 3 Materials and methods

To check the correctness of the proposed solutions, a test task for low-rise construction projects in a rural village was developed. Each project includes a one-, two-, or three-story residential building with 2, 3, 4 rooms on each floor and three types of outbuildings (Figure 1). The designations of work in the project columns in Figure 1 are associated with the following types of activities (the numbering of the listing items corresponds to the work numbers):

1. digging foundation pits, removing soil, building foundations and basements for buildings and outbuildings, building access roads for the construction (installation) of buildings and structures;
2. construction (installation) of personal buildings;
3. construction and arrangement of roofs of personal buildings;
4. finishing of interior premises of personal buildings;
5. installation of electrical wiring, heating, sewerage, water supply and connection of communications of personal buildings;
6. construction (installation) of the 1st floor of the building;
7. construction (installation) of the 2nd floor of the building;
8. installation of electrical wiring, heating, sewerage and water supply to the premises of the 1st floor of the building;
9. construction (installation) of the 3rd floor of the building;
10. finishing of the interior of the 1st floor of the building;
11. installation of electrical wiring, heating, sewerage and water supply to the premises of the 2nd floor of the building;
12. construction and arrangement of the roof of the building;
13. finishing of the interior of the 2nd floor of the building;
14. installation of electrical wiring, heating, sewerage and water supply to the premises of the 3rd floor of the building;
15. landscaping of a personal plot, including the construction of a fence;
16. finishing of the interior of the 3rd floor of the building;
17. connection of building premises communications;
18. landscaping of the attic and finishing of the premises.

Depending on the number of floors of the building, two technological breaks are provided:

19. P1 – between work 1 and works 2 and 6;
20. P2 – between works 7 and 9.

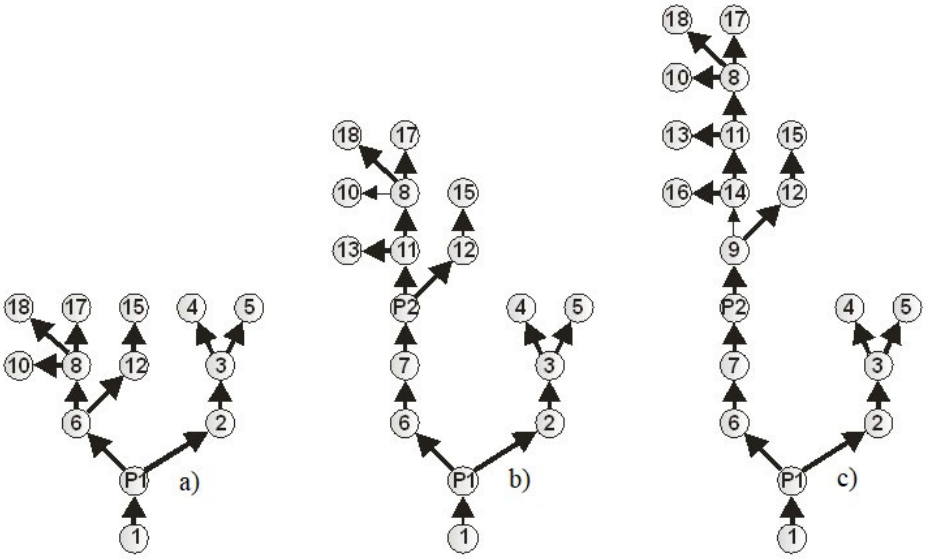


**Fig. 1.** Graphs of projects of buildings and personal buildings: a – one-story building; b – two-story building; c – three-story building.

For numerical experimentation, a model of a multi-project planning program has been developed. The layout contains a relational database (DB) and tools for interactive data entry into the DB. The layout also includes tools for visualizing the results of generating a calendar schedule and resource consumption diagrams.

## 4 Results and discussion

For numerical experiments, a test task was used, including 27 projects, representing all options for combinations of residential buildings and household buildings. The assignment includes 504 requests for project work. The following resources were used to implement the projects: 266 workers of 13 specialties, 107 construction mechanisms of 10 types, 193 sets of construction tools of 8 types. All specified information is entered into the layout database.

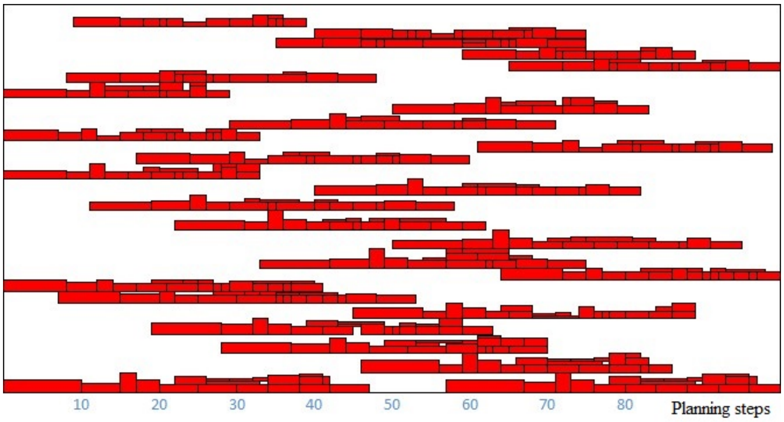


**Fig. 2.** Gantt chart of the initial calendar schedule of the test task.

Figure 2 shows the initial calendar schedule visualized by the layout in the form of a Gantt chart, in which individual projects are represented by their aggregations according to the consumed volumes of financing. Figure 3 shows the tick-by-cycle funding requirement for the initial schedule.

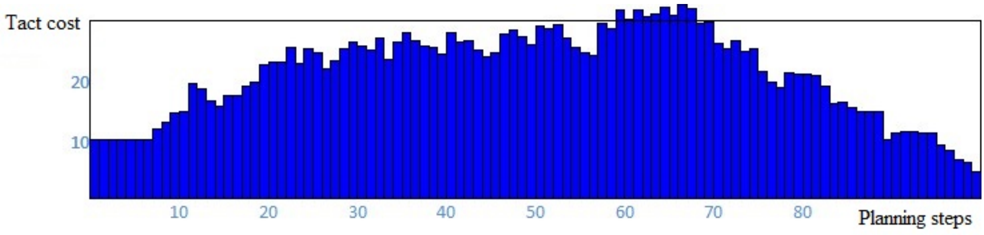


**Fig. 3.** Funding required at each tick in the initial calendar schedule.

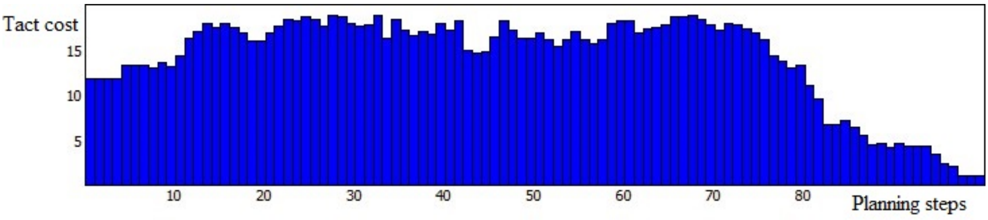


**Fig. 4.** Funding required at each cycle in an optimized calendar schedule.

Analysis of Figure 3 and Figure 4 shows that for the implementation of all 27 projects of the task, 80 planning cycles are sufficient instead of the accepted schedule interval of 100 planning cycles to ensure uniformity of cycle-by-cycle financing.

The capabilities of the developed algorithms and layout can be judged from Figure 5.

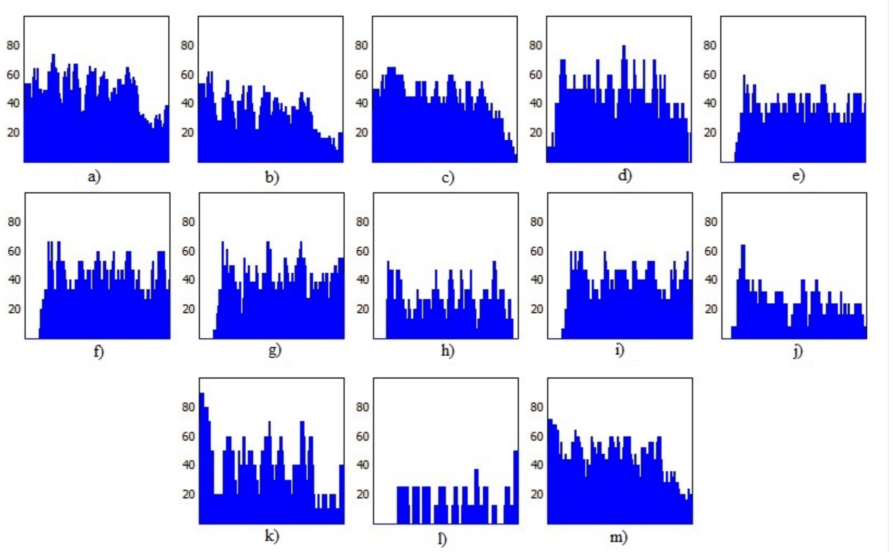


**Fig. 5.** Per-cycle employment of workers in an optimized calendar schedule: a – auxiliary workers; b – masons; c – crane operators; d – welders; e – electricians; f – plumbers; g – plasterers; h – installers; i – carpenters; j – roofers; k – excavator operators; l – bulldozer drivers; m – drivers.

## 5 Conclusion

Based on the results of the calculations for the test task, the layout can represent the consumption of all types of resources.

Thus, the following results were obtained:

- the formalization of the tasks of forming and optimizing the calendar schedule for multi-project planning was carried out;
- general approaches and algorithms for solving problems of generating calendar schedules using ranking methods of decision-making theory are presented;
- a test task was prepared in the form of a set of low-rise development projects;
- a model of a multi-project planning program has been developed. The test task data is entered into the layout database;
- the results of centralized multi-project planning of low-rise development projects are visualized.

By way of discussion, the following questions/problems should be addressed:

- the validity of using two strategies for generating schedules - the formation of an initial calendar schedule and its subsequent optimization;
- choosing when to include the first project in the initial schedule;
- conditions for the need to use multi-pass optimization;
- assessment of the need to implement a decentralized approach in multi-project planning.

## References

1. Z.K. Petrova, *Fundamentals of the development of low-rise urban planning: monograph* (Moscow, 2013)
2. Yu. Bocharov, Z. Petrova, *Priorities for the development of low-rise buildings in Russian urban planning. Fundamental, search and applied research of the RAASN on scientific support for the development of architecture, urban planning and the construction industry of the Russian Federation in 2017* **1** (ASV, Moscow, 2018), pp. 310-314
3. A. Repin, Transport Business of Russia **1**, 12-15 (2015)
4. Z. Petrova, V. Dolgova, Academia, Architecture and Construction **2**, 115-125 (2018)
5. A. Teryagova, V. Salova, *Architectural and urban planning aspects of the formation of a low-rise residential environment for the "Society of all ages" in the Samara region*, in a collection of articles of the 79th All-Russian Scientific and Technical Conference, Samara, Russia, pp. 229-237 (2022)
6. N. Klevanskiy, L. Voloshchuk, *Centralized multi-project planning of low-rise development of rural areas*, in Nikon readings, pp. 348-352 (2019)
7. N. Klevanskiy, A. Krasnikov, Fundamental Research **2-3**, 482-486 (2016)
8. N. Klevanskiy, Journal of Advanced Research in Technical Science **6**, 70-75 (2017)
9. T.R. Browning, A.A. Yassine, International Journal of Production Economics **126 (2)**, 212-228 (2010)
10. V.M. Dalfard, V. Ranjbar, Tehnički vjesnik **19(3)**, 493-499 (2012)
11. R.K. Chakrabortty, R.A. Sarker, D.L. Essam, Resource Constrained Multi-project Scheduling: A Priority Rule Based Evolutionary Local Search Approach. In: Leu G., Singh H., Elsayed S. (eds) Intelligent and Evolutionary Systems. Proceedings in Adaptation, Learning and Optimization **8** (Springer, Cham, 2017), pp. 75-86.

12. A. Singh, *Resource Constrained Multi-Project Scheduling with Priority Rules & Analytic Hierarchy Process*, in Proc. of 24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013, Procedia Engineering **69**, 725-734 (2014)