Digitalization of process management in the agro-industrial complex

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Abstract. The article is devoted to the consideration of the current problem of developing heuristic approaches in operational scheduling of production processes. The purpose of the study is related to the development of methods and algorithms for generating schedules for an arbitrary number of request vectors. The problem was formulated and formalized using scheduling schemes and priority rules. For numerical experimentation, a model of a program for generating a railway schedule and a test task were developed, including 4573 applications for weekly schedules of a railway network containing 100 stations, 128 hauls between stations, 100 passenger routes of different frequencies, 471 trains per week. The developed program model, in addition to carrying out calculations using the presented algorithms, visualizes the results of numerical experimentation in the form of spiral representations of station and haul schedules. The performance of the developed methods and algorithms has been confirmed. Conclusions and discussion of the study results are presented.

1 Introduction

The state agricultural policy of the Russian Federation is aimed at creating a model of sustainable and effective development of agriculture and rural areas in accordance with the Federal Law "On the Development of Agriculture" dated December 29, 2006 N 264-FZ (as amended on July 20, 2018). This determines the strategic level of process management in the agro-industrial complex. These processes primarily include production processes. Functionally, production process management, like any management problem [1], includes: planning, organization, control, operational regulation, motivation. Planning is the process of making specific decisions related to ensuring the effective functioning and development of an economic entity. Quite a large number of studies have been devoted to the issues of managing production processes and their planning in various sectors of economic activity,

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for example [2-6]. Depending on the level of decision-making, strategic, current and operational scheduling are distinguished.

According to the GOST 14.004-83 standard, the production process is the totality of all actions of people and tools necessary at a given enterprise for the manufacture and repair of products. The production process includes the following stages:

1) preparation of production,
2) logistics of production,
3) manufacturing of parts,
4) assembly of components and products as a whole,
5) testing of finished products and their packaging,
6) other activities related with the manufacture of products manufactured by the enterprise (painting, preservation, etc.).

According to GOST 3.1109-82, a technological process is a part of the production process that contains targeted actions to change and (or) determine the state of the subject of labor. Objects of labor include blanks and products. The technological process can be related to the product, its component part, or to methods of processing, shaping and assembly. The technological process is divided into the following components: technological operations, installations, technological and auxiliary transitions, working and auxiliary moves, positions and techniques. A technological operation is a completed part of a technological process performed at one workplace.

A technological operation is the basic unit of production planning and accounting. Based on the operations, the labor intensity of manufacturing products is determined and time standards and prices are established, the required number of workers, equipment, fixtures and tools is set, the cost of processing is determined, operational scheduling of production is carried out, and quality and timing of work are monitored.

According to the GOST 14.004-83 standard, the workplace is an elementary unit of the enterprise structure. Performers of work, serviced technological equipment, as well as equipment and labor items for a limited time are located at the workplace.

The problem of constructing a production schedule is solved with the help of operational scheduling and is an important link in enterprise management. Solving the problem of operational scheduling requires taking into account many external and internal factors, and, above all, the organization of the actual technological production processes.

Operational calendar planning should ensure the synchronous operation of interacting areas for the reliable functioning of the entire economic object (shop, enterprise) as a whole [7, 8]. Mathematical problems of operational scheduling are predominantly solved on the basis of models of scheduling theory and resource (inventory) management.

To summarize, it should be noted that the technological process can be represented by a vector of technological operations and jobs associated with them.\

Most scheduling problems are tasks of forming and optimizing the process of servicing a finite set of requirements (requests) for the implementation of actions (works, events, operations) in a system containing limited resources. For each requirement, valid sets of resources are indicated as initial data, and the requirement servicing schedule is a one-to-one mapping in which each requirement is assigned an action with a defined set of resources in a certain period of time (timeslot). In some scheduling tasks, a single requirement may generate several time-separated and interrelated activities. Requirements may be associated with varying amounts of system resources required.

Similarly, we can note a one-to-one mapping in which each action or group of interrelated actions of the schedule corresponds to the original requirement (requisition).

Depending on the subject area of the processes being serviced, two types of scheduling tasks are possible:

- performance tasks (minimizing the schedule interval) for servicing requirements;
- tasks on the efficiency of servicing requirements for a specified time interval within which a schedule is generated.

The article will consider problems of the second type, in which the efficiency of servicing requirements depends, first of all, on the efficiency of using system resources.

Differences in solving scheduling problems are determined by the type of connections between scheduling requests:

1. a schedule is a set of actions independent of each other. That is, any schedule action can be located in any timeslot of the schedule interval. This type includes schedules for exams, school classes, etc. This type is characterized by the ability to arbitrarily select applications when creating a schedule. The same applies to the selection of schedule elements when optimizing it;
2. a schedule is a set of action vectors independent from each other, which are elements of the schedule. For example, a transport schedule, a calendar schedule for performing operations of a set of technological processes. The schedule will be formed from vectors of requests, each of which includes the execution time (duration) and the set of resources required for this. Formation of the schedule is associated with the choice of request vectors. Schedule optimization is carried out by selecting and rearranging schedule elements - action vectors;
3. a schedule is a set of network structures of actions independent from each other. This type of schedule includes, for example, a calendar schedule for the construction of village buildings or, in general, multi-project planning. When creating a schedule of this type and optimizing it, the network structures of requests and actions should be considered using ranking methods of varying complexity. The elements of the schedule (calendar schedule) will be network structures of actions.

The main task of operational scheduling is related to the need to ensure rhythm and uniformity of production.

The uniformity of production is ensured by minimizing deviations of product output from the schedule. The rhythm of production is ensured by minimizing deviations in the volume of production over equal periods of time at all stages of the production process. Both indicators can be used as objective functions and integral estimates of the production schedule.

In [9], the NP-complexity of the operational scheduling problem was noted. The reason for this complexity is the multicriteria nature of scheduling problems in general, and as a consequence, the need to use various types of heuristics is indicated. In [10] a description of some heuristic methods used in operational scheduling is given. In [11], the concept of scheduling various types is presented.

It should be noted in passing that the expanding use of multi-criteria approaches in the field of agro-industrial complex [12-17].

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.

The SGS_1 scheme uses two priority rules PR_{11} and PR_{12}. In each SGS_1 cycle the following is carried out:

- preparation of initial data for rule PR_{11} – determination of route congestion criteria;
- in rule PR_{11}, the most loaded route in terms of the required transport network resources is selected among the routes not included in the initial schedule;
- preparation of initial data for rule PR_{12} - determination of criteria for the uniformity of the initial schedule in the daily traffic interval of the route selected by rule PR_{11};

- rule PR_{12} determines the departure time from the starting point of the route selected by rule PR_{11}, ensuring the greatest uniformity in the consumption of transport network resources.

The purpose of the article is to present the developed methods and algorithms for generating schedules for an arbitrary number of request vectors in a system with limited resources.

2 Statement and formalization of scheduling problems for vectors of requests

The basis of heuristic approaches [11] is the use of schedule generation schemes (SGS - schedule generation scheme) and priority rules (PR - priority rules). The priorities in this context are the criteria for determining the order of execution (inclusion in the calendar schedule) of request vectors competing for resources. The criteria are formed from scalar values of various characteristics of applications, including allocated and required resources. Priority rules mean certain sequences of techniques and methods for determining the order of inclusion in the production schedule of request vectors competing in terms of resources.

To generate a production schedule, two sequentially applied schemes for generating schedules are proposed. SGS_1 – scheme for generating the initial production schedule; SGS_2 is a production schedule optimization scheme.

The SGS_1 scheme uses two priority rules PR_{11} and PR_{12}. In each SGS_1 cycle the following is carried out:

- preparation of initial data for rule PR_{11} - determination of criteria for the workload of technical processes;
- in rule PR11, the most loaded technical process in terms of required resources is selected among the technical processes not included in the initial schedule;
- preparation of initial data for rule PR_{12} – determination of criteria for the uniformity of the initial schedule in the schedule interval for the technical process selected by rule PR_{11};
- rule PR_{12} determines the start time of the technical process selected by rule PR_{11}, ensuring the greatest uniformity in the consumption of production resources.

The SGS_2 scheme also uses two interrelated priority rules PR_{21} and PR_{22}. In each SGS_2 cycle the following is carried out:

- preparation of initial data for rule PR_{21} - determination of criteria for the uniformity of technical processes in the schedule;
- in rule PR_{21}, the most uneven resource consumption process is selected;
- preparation of initial data for rule PR_{22} - determination of schedule uniformity criteria when moving the start time of execution of the technical process selected by rule PR_{21} in the schedule interval;
- rule PR_{22} determines the start time of execution of the technical process selected by rule PR_{21}, at least not worsening the integral assessment of the uniformity (uniformity criterion) of the schedule.

The operation of the circuit is completed either after one pass - rearrangement of all technical processes, or after several passes.

3 Materials and research methods

To check the correctness of the proposed solutions for generating schedules for request vectors, a test task was developed that simulates the movement of passenger railway transport

[18]. The test task includes 4573 requests for weekly schedules of a railway network containing 100 stations for boarding and disembarking passengers, 128 runs between stations, 100 passenger routes of different frequencies, 471 trains per week.

For numerical experimentation, a model of a program for generating a railway schedule 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 station and haul schedules.

4 Research results and discussion

To visualize schedules of stopping points and transfers between them, spiral representations (Figure 1) were used, in which the spiral is the time axis. The length of the spiral is equal to the value of the schedule interval. A turn of the spiral is a period of the schedule. Markings on the spiral can represent the arrival/departure of a vehicle.

In Figure 1 shows a visualization of the schedule of the busiest station in the initial schedule of passenger transport of the test task's railway network obtained by the mock-up. The schedule shown is weekly, and each turn of the spiral sequentially represents the daily schedule. Blue represents the arrivals/departures of one train at a station, yellow – two trains simultaneously at the station.

Analysis of Figure 1 leads to the conclusion about the need to ensure uniform use of station resources. Achieving uniform use of station resources is possible by ensuring equal intervals between train arrivals.

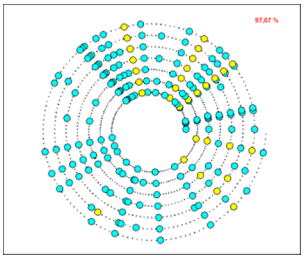

Fig. 1. Initial station schedule [19].

By introducing the standard deviation from the average interval as estimates of station uniformity and criteria for train uniformity across all stations on the route, it is possible to select the most uneven train. For this train, the departure time from the initial station is determined using a multi-vector ranking of uniformity criteria across all stations and sections of the route. In Figure 2 shows a visualization of the schedule of the same station after optimization by the layout of the initial schedule of the railway network of the test task (Figure 1).

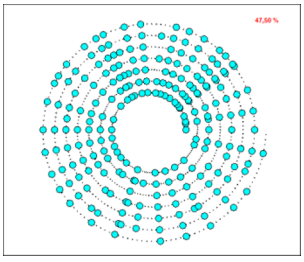

Fig. 2. Station schedule in optimized schedule [19].

5 Conclusion

Thus, the following results were obtained:

- formalization of the tasks of generating and optimizing the schedule for vectors of requests was carried out;
- general approaches and algorithms for solving problems of generating a production schedule using ranking methods of decision theory are presented;
- a test task was prepared in the form of a dataset about the railway network;
- A model of a program for generating a railway timetable has been developed. The test task data is entered into the layout database;
- the results of the formation of the railway schedule 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 schedule and its subsequent optimization;
- choosing the time to include the first technical process in the initial schedule;
- conditions for the need to use multi-pass optimization;
- assessment of the need to implement a decentralized approach in operational scheduling.

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