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Data Processing Models and Algorithms for Outsourcing of Resources in the Production Scheduling Task

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Abstract— **Production scheduling is often used to improve the efficiency of an enterprise. The task of production processes scheduling of an aircraft engine enterprise is considered in this article. Aircraft engine consists of a large number of different parts and assemblies (more than 100,000) that are manufactured in several production areas of various specializations. It is necessary to plan the work of the workshops so that the parts are manufactured by the same time to ensure assembly. Various abnormal situations often occur during the production process at the enterprise. These situations, together with the incorrect distribution of parts between workshops, can make a significant imbalance in the production of the final product. The solution to the problem of balancing the production plan of the workshop is possible using the model of inter-site outsourcing. The models and data processing algorithms based on multi-agent approach are proposed to solve the production scheduling problem with inter-site outsourcing.**

Keywords—resource management, manufacturing scheduling, resource outsourcing, multi-agent approach

I. INTRODUCTION

The main factors of long-term development of the company are competent strategic management, innovation, production efficiency, qualification of employees and investment, including in information technology. Therefore, the main tasks of the domestic machine-building complex are: development of high-tech products, modernization of equipment and technologies, strengthening of market positions, as well as the influx of qualified personnel.

The effectiveness of the production organization depends primarily on the quality of production scheduling, resource allocation, and uniform capacity utilization in the manufacture of parts.

The individual characteristics of personnel with the same qualifications and equipment of the same type are not taken into account in production scheduling.

This factor is very important. In real life, people of the same qualifications can work at different speeds, quality and have their own preferences in work. The same type of equipment may also have limitations in terms of dimensions, weight of parts, quality of production, etc. All this affects the final plan.

The development of resource management software that takes into account these factors will improve the quality of scheduling and the efficiency of the production process.

II. PROBLEM DESCRIPTION

The main task of scheduling the production site of the workshop is to allocate available resources to fulfill the production plan for the manufacture of parts [1].

Let's consider the task of scheduling on the example of an aircraft engine company. The commercial product of such an enterprise is a complex aircraft engine (motor kit). The technological process of manufacturing and assembling an aircraft engine is characterized by the following indicators:

- the number of parts is appriximately 6.5 thousand types, the total number of parts is more than 75 thousand;total number of operations of all technological processes – more than 46 thousand (424 unique operations);
- number of unique operations over 400; the total number of operations of all technological processes is more than 46 thousand;
- the number of used tools is more than 53 thousand;
- the number of personnel involved is about 21 thousand;
- the total number of technological equipment involved is more than 2 thousand machines, each workshop can have from 50 to 280 machines, depending on its size and purpose.

Each motor kit consists of a large number of parts and assembly units (PAU). Most PAUs are complex and laborious to manufacture. Therefore, the production cycle for the manufacture of each engine kit is approximately 1.5 years.

The company can produce several types of engines. Many workshops, equipment, personnel, and tools are involved in the production of each motor kit.

A modern aircraft engine manufacturing company is a fairly well-coordinated mechanism. But many emergency situations can occur in production over such a long period of time (1.5 years). For example: failure of unique equipment, lack of tools, materials or other resources, including personnel. Such abnormal situations can create a strong imbalance in the work of production sites, workshops and the enterprise [2].

Let's consider the process of manufacturing parts in the workshop.

The execution time of any machining operation of a part (for example, turning) consists of the following steps:

1. setup time is the time required to install and configure device on the machine;

2. installation time is the time required to clean the device from chips and install the part on the machine;

3. operation time;

4. the time of removal of the part;

5. time to remove the device after the operation.

Preoperative installation and postoperative removal of the devices have a sufficiently long duration. Parts are set in batches to reduce unproductive time. The batch size depends on the duration of the operation. For example, the duration of the sum of time 1 and 5 should be about 20% of the time 2–4 for the entire batch.

A batch can consist of 1-2 parts or can be divided into several batches in case of lagging behind the production schedule. In this case, the setup time and postoperative removal of the device is spent for each batch, and even for each part. This increases the time that is not associated with the manufacture of parts when the equipment is busy. Similarly, the working hours of the installers are growing.It is also possible that, when performing work on reconfiguring parts, the installer transfers the setup time for another machine, since several machines are assigned to one installer.

Thus, a simple, lagging behind the schedule entails serious consequences associated with the risk of the subsequent impossibility of timely stocking of products, as well as an increase in the load on the planned workshop services.

The developed system of scheduling should take into account all the specifics of the subject area: properties of parts, resource schedules, qualifications and staff productivity. These characteristics can change over time and have a significant impact on the production time of each individual PAU and the production cycle of the engine as a whole.

The main part of the scheduling process is the selection of the necessary suitable resources for performing operations of the technological process. When choosing a suitable resource (from the many available), it is necessary to check the category of the resource, the values of the "quality" and "performance" parameters for compliance with the required ones. All resources are checked in such way.

The resource is selected so as to reduce the time of the operation (parameter "performance") without losing the required quality (parameter "quality"). Resource availability is also taken into account. This can be achieved by exhaustive search of all resources related to the desired category.

According to estimates, the number of such enumeration of resource options for each operation can reach 200. To complete the operation several resources (2-3) are used. There are 10–20 operations to produce one part, and a monthly manufacturing plan can reach 1000–2000 nomenclature items. Thus, the number of checks of resource parameters necessary for the preparation of the schedule can be 4,000,000 ÷ 24,000,000. This will require a long time from 1 to 7 hours [3].

The mathematical model [1], [4], information and algorithmic support [5] have been developed earlier to solve the problem of scheduling production processes. It is proposed to use a multi-agent approach when developing software [4].

III. USING A MULTI-AGENT APPROACH TO SOLVE THE TASK

Agents are active objects (software modules) [6] that can initiate purposeful activity to perceive the environment and influence it. They have the following «mental» properties (or a subset of them):

- **knowledge** is the permanent, unchangeable agent's knowledge about itself, the environment, and other agents;
- **beliefs** are an agent's knowledge of the environment (including other agents) that may change over time and become incorrect;
- **desires** are the states that the agent wants to achieve (may be contradictory), similar to goals;
- **commitments** are the tasks that the agent undertakes in cooperation with other agents at their request or on instructions of them;
- **intentions** are the actions that are going to be performed as a result of their desires or because of their commitments.

Multi-agent systems (MAS) are self-organizing systems, because they are looking for a solution to the problem without external intervention. The main advantage of MAC is flexibility. A multi-agent system can be supplemented and modified without rewriting a significant part of the program. Also, these systems have the ability to self-repair and are resistant to failures, thanks to a sufficient stock of components and self-organization.

The agents are implemented as separate independent threads of the same class (type), which are endowed with various mechanisms necessary for interacting with each other or (if available) other thread classes (agents).

The main types of agents of a multi-agent system and their inherent properties were identified to solve the scheduling problem [5]: detail, operation and resource.

The operation of manufacturing the detail(s) can be represented as an independent agent. It is able to work independently and select everything necessary for the work. If each such operation independently selects the necessary resources for execution, the selection of resources will be performed in parallel. Time for this will be significantly reduced compared to the sequential selection of resources.

The experiment was conducted whith the resource allocation sequentially and in parallel by independent flows in various combinations [3]. The experiment showed the feasibility of using a multi-agent approach to solve the problem of resource allocation. The experimentally simulated situation showed that the speed of selecting resources for the task when applying the multi-agent approach was approximately four times higher compared to sequential sorting.

In addition, studies of the use of multi-agent technologies show high adaptability of systems [7] and the effectiveness of results in the following areas [8]: planning logistics operations (sea tankers, taxis, freight, trains); car rental planning; analysis of Big Data; understanding the semantics of natural language text; designing complex products; supply chain planning; satellite constellation planning; management of mobile teams; R&D project management and others.

IV. FORMALIZATION OF THE DATA PROCESSING MODEL FOR INTER-DIVISION COOPERATION

There are a number of methodologies and standards for modeling complex systems. These standards include the IDEF (Integration Definition Metodology) modeling methodology. The IDEF methodology allows you to study the structure, parameters, and characteristics of production, technical, and organizational-economic systems.

The general IDEF methodology consists of particular modeling methodologies based on a graphical representation of systems. They allow you to effectively analyze and display the activity models of a wide range of complex systems. In this case, the developer himself determines the breadth and depth of the investigating of the processes. This allows not to overload the created model with redundant data. Currently, the IDEF family includes 14 standards [9], [10].

The IDEF0 standard allows to fully and visually present the system in a graphical form, so it is chosen for modeling the production scheduling process.

Existing situation

It is required to develop a production schedule based on available information on production volumes. It is necessary to take into account the technical, technological and other production limitations of the subject area when planning. The decomposition of the top-level context diagram, which describes the main steps in solving the problem, is presented below (see Fig. 1).

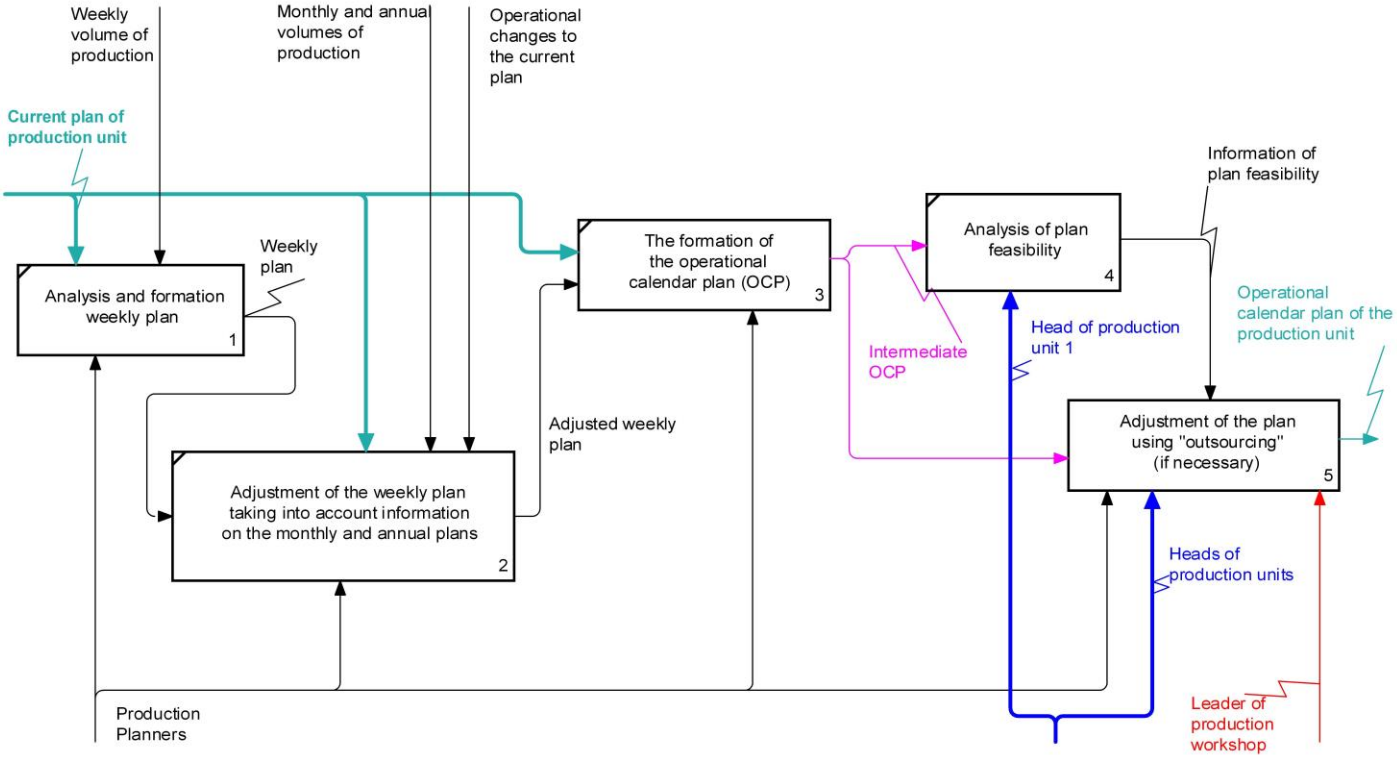

Fig. 1. Structure of the process of developing an operational calendar plan.

Stage 1. The planner performs an analysis of the specified items, volumes, and makes a weekly plan, taking into account possible balances from the previous week. The planner is not a technical specialist, so he often does not take into account any aspects related to equipment features, preferences of workers, and other informal features of the subject area.

Stage 2. The planner compares the specified weekly volume with the monthly / annual program (volume) and, determines the share of the specified weekly volume in the monthly/annual volume of the corresponding nomenclature. If this share is small, then he can decide to increase the manufactured batch of details.

For example, weekly volume of production of the details «nipple» is 20 PCs in the manufacturing of this part has the operation «Trimming the end face» with a duration of 0.5 min, thus making this operation on the whole batch would take 10 minutes. The time required for setup of the machine is 30 minutes. It is obvious that it is not advisable to take the machine 40 minutes when its useful load is 25% of this time. Therefore, it is necessary to increase the share of the payload. To do this, the planner shifts to an earlier date the projected volume of relevant details in the following weeks/months.

Parts for different engines are often unified in the aircraft engine industry. For example, fasteners, pipeline fittings, and other PAU. Such parts have the same geometric dimensions, are made with the same tooling, but have different ciphers. Therefore, the planner can increase the payload of the machine by selecting similar parts from different engines and combining them into one batch.

Stage 3. The planner makes a calendar plan for the production of parts with the assignment of operations to the workers. But he can only predict the movement of parts during the day in the following context: «the Operation will be performed on Tuesday». Therefore, he can plan the next operation only for the next day. Taking into account the inaccuracies with which the OCP is compiled at stage 3, as well as the limited resources in the production shop, such a OCP, to checked at **stage 4**, often turns out to be impossible. The planner, together with the production unit head, analyzes the resulting OCP by fully comparing the specified positions and the positions distributed by performers. The information received at this stage about the performance is the control effect for **stage 5**.

The diagram of the decomposition of the process of adjusting the OCP using «outsourcing» is presented in Fig. 2.

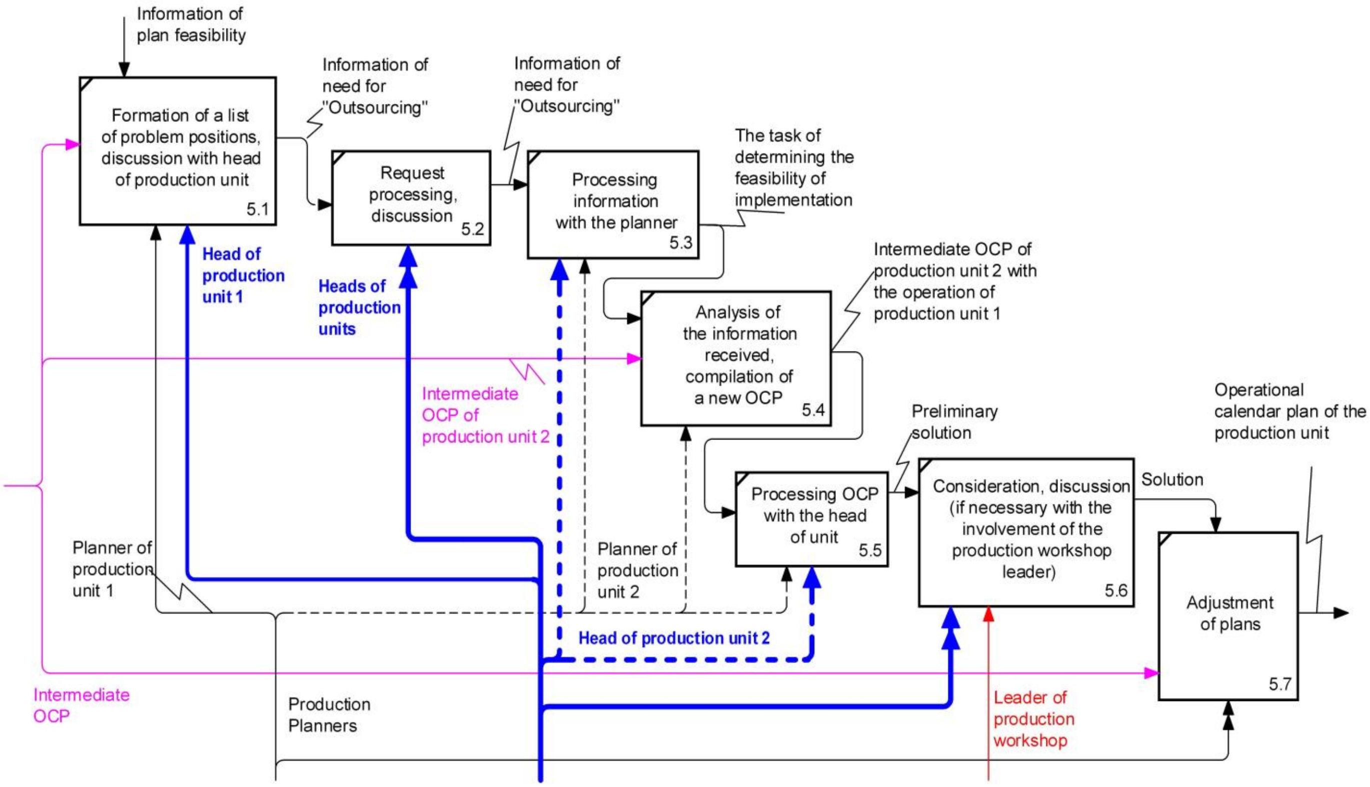

Fig. 2. Structure of the OCP adjustment process using «outsourcing».

Stage 5.1. The planner and the production unit head make a list of problem items and determine whether they can be performed on their own or whether they need to ask for help from an adjacent production unit. The input data is an intermediate OCP, and the control action is information that the resulting intermediate OCP is not feasible. Output data – making a decision about the need to attract an adjacent production unit.

Stage 5.2. The head of the two production units are discussing the need to transfer the details of production unit 1 for manufacturing to production unit 2.

Stage 5.3. The head of production unit 2 passes information about the details to his planner (production routes, availability of workpieces, etc.), which they discuss together in stage 5.3.

Stage 5.4. The planner of production unit 2 analyzes the information received and adds new details to the OCP of his production unit. He uses the same methods when integrates details as when making its «own» OCP.

Stage 5.5. The planner of production unit 2, after received the OCP, considers with his supervisor, explains the risks of not fulfilling own plan, the time of production of the received nomenclature, and other information. At this stage, the head of production unit 2 is already making a preliminary decision about whether he can accept parts for production.

Stage 5.6. After receiving the OCP, the head of production unit 2 meets with head of production unit 1 and discusses the possibility of implementing the plan. The head of of production unit 2 is often not interested in production someone else's nomenclature, so to make a final «strong-willed» decision, the head of production unit 1 may be forced to involve the head of the shop.

Stage 5.7. After receiving the decision to transfer the nomenclature (possibly partial), the planners of both production units adjust their OCP to take into account the transfer of the item between production units in accordance with the received decision.

Thus, the staff is forced to conduct numerous negotiations, incur large time, intellectual and psychological costs when the weekly OCP is constructed. The duration of Stage 5 is approximately 6.5 hours [2] and does not ensure 100% correctness and implementation of the received plan.

Target situation

The process of automatically drawing up the OCP using the decision support system (DSS) and with minimal staff involvement is described next. The managers mostly make decisions about the transfer of the item, planners enter the initial information, and can also adjust the plan.

Task: it is needed to develop a production schedule based on existing information about production volumes. The technical, technological, and other production constraints of the subject area must be taken into account when planning.

The decomposition of the top-level context diagram that describes the main stages of solving the problem using the DSS is presented in Fig. 3.

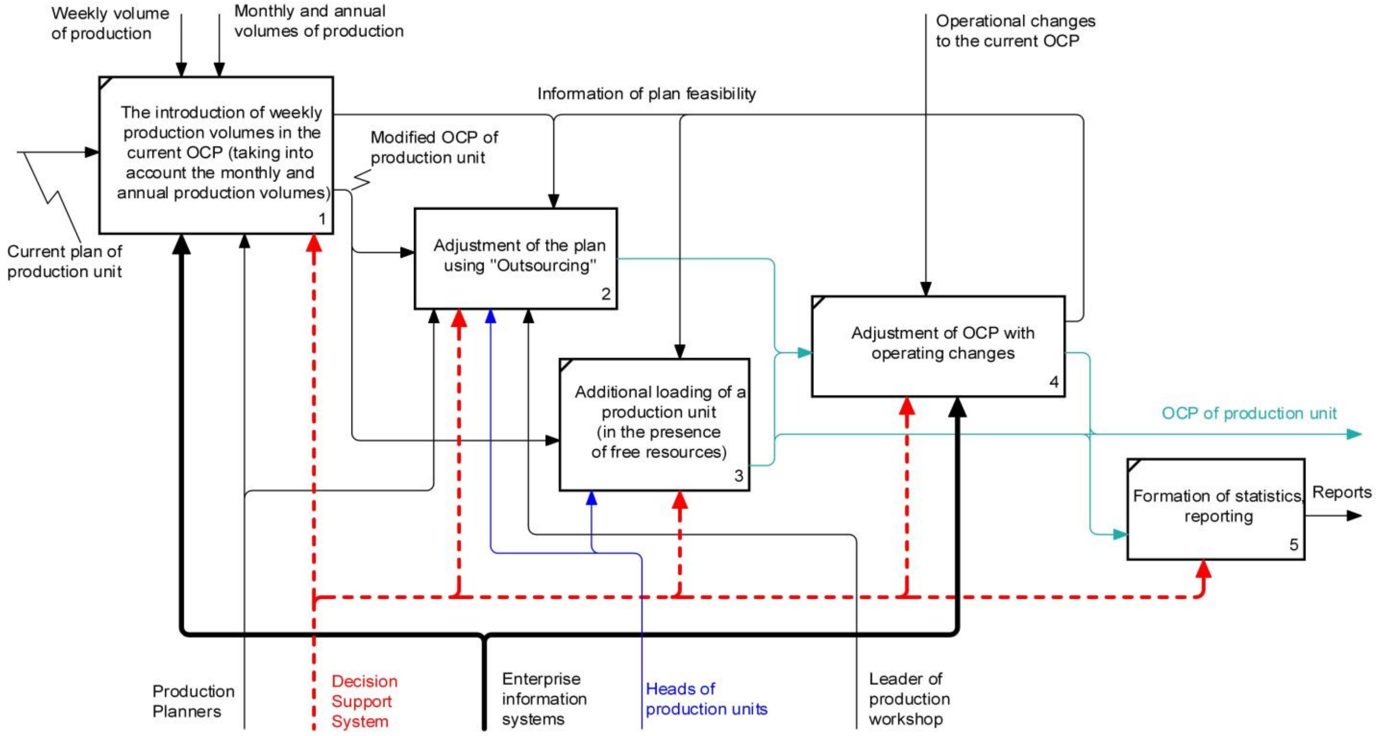

Fig. 3. Setting of task for operational calendar planning using a decision support system.

Stage 1. DSS downloads from the enterprise's servers the information on the nomenclature that needs to be produced [2], performs its analysis, volumes and draws up a weekly plan, taking into account possible balances from the previous week. The DSS uses information on the condition of equipment, staff qualifications and preferences, characteristics of parts and other available information about the features of the subject area to draw up the weekly OCP.

DSS performs for each operation the calculation of the employment of equipment during the planning process according to the formula:

$$C_{EE} = \frac{T_{MASH}}{T_{TOTAL}} \qquad (1)$$

T_{MASH} is machine run time for a batch of parts

T_{TOTAL} is total time occupied of equipment

$$T_{TOTAL} = T_{MASH} + T_{PF} \qquad (2)$$

T_{PF} is preparatory-final time, it is the time required to install the device on the machine, prepare the machine before performing the operation, as well as removing the device and cleaning it after manufacturing the part.

DSS can propose to increase the volume of manufactured parts in a batch if the recommended coefficients for the use of equipment are not achieved: 0,5 and higher for simple universal equipment; 0.8 and higher for CNC machines and machining centers (on equipment with removable pallets can be close to 1).

The DSS searches for analogous parts among the entire set plan, or plans to perform the same parts earlier from the next months. It also provides recommendations about the need to order additional workpieces. The output data of this stage is the OCP and information about its feasibility, which in turn is the control effect for the next stage.

Stage 2. If an impossible plan is received, planners and heads of production units perform preliminary planning based on the DSS data, taking into account the one-time transfer of the item to another production unit for «outsourcing».

Stage 3. If there are available resources, the OCP module of production unit 1 (MOCP_1) requests additional work from the OCP module of another production unit (MOCP_2). DSS_1 and DSS_2 can make recommendations about one-time transfer of parts from PUnit_2 to PUnit_1 when production unit 2 is overloaded (overtime or weekend work is planned, or the plan is not feasible on time). The final decision is made by the production unit heads.

Stage 4. The OCP is being adjusted for operational changes (urgent production of a spare part, bulkhead of a rejected product, etc.). The adjustment is based on information received from the company's information systems.

The OCP formed at stage 4 is the output of the «Operational-Scheduling» process and is input to stage 5.

Stage 5. The statistics are kept and reports are generated.

The decomposition diagram of the plan adjustment process using «Outsourcing» when using DSS is presented in Fig. 4.

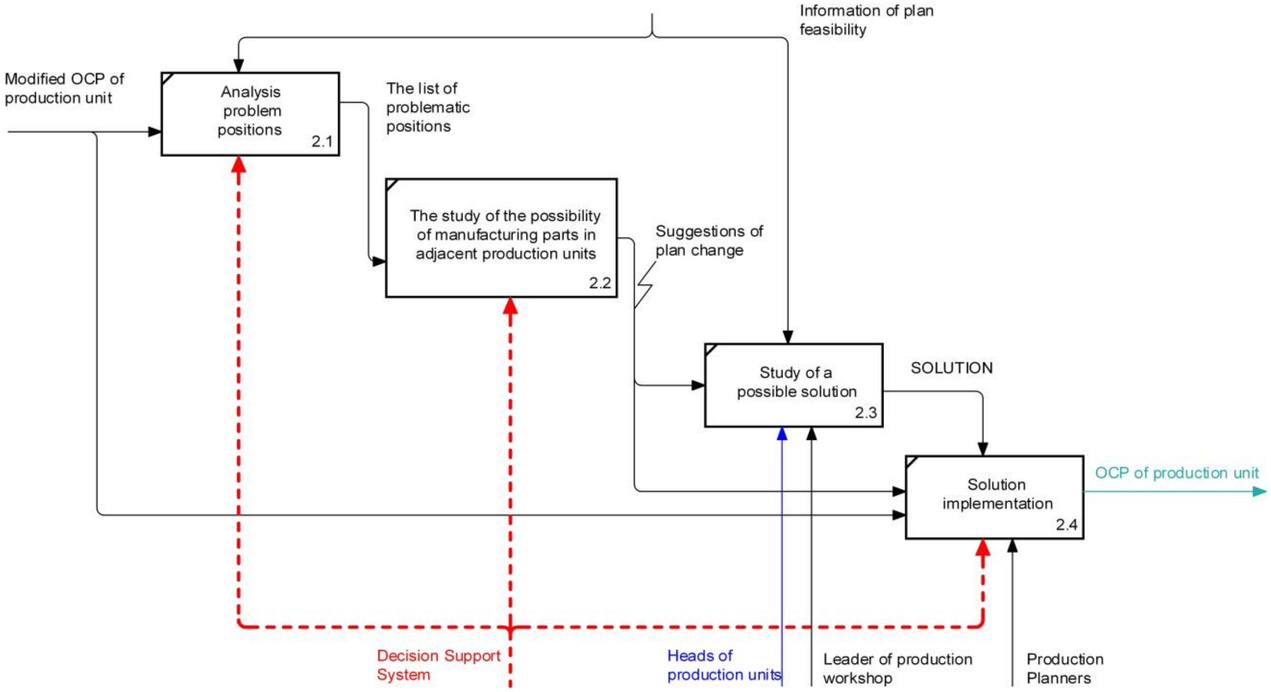

Fig. 4. The structure of the process «Adjustment of the plan using» Outsourcing «(when using DSS).

Stage 2.1. The input data is the OCP, formed on the basis of the set weekly and monthly/annual production volumes. MOCP_1 analyzes and identifies problematic positions that are not feasible in the plan. The list of impossible positions is the input data for stage 2.2.

Stage 2.2. MOCP_1 analyzes the technical and actual possibilities of fulfilling the plan: technical - the ability of available resources to perform this operation, actual - checking the availability of resources or their analogues. MOCP_1 forms a recommendation to change plans for both its own and another production unit and passes the decision to the elaboration of MOCP_2 in the case of a possible solution. At the same time, it is possible that this solution does not fully meet the specified requirements - both production units may become not fulfilling the plan, but will retain the general rhythm of production.

Stage 2.3. MOCP_2 is working on the possibility of fulfilling its own plan with the added nomenclature of production unit 1. After that DSS_1 and DSS_2 generate a report for discussion of the leaders of the production units on the feasibility/unfulfillment of the plan. Heads reach an agreement on the transfer of nomenclature in full or perhaps not the proposed volume through negotiations. If an agreement cannot be reached, a production workshop leader can be involved.

The decision to transfer the nomenclature is the control action for stage 2.4. Planners enter the necessary information into the relevant MOCP. MOCP makes the plan.

The estimated duration of the plan adjustment with "outsourcing" (stage 2) and using DSS is 1.2 hours. The duration may increase due to the employment of the production workshop leader, as perhaps he will not be able to accept the heads of the production units immediately when necessary [2].

V. CONCLUSION

The formal formulation of the resource management problem for production scheduling. A data processing model is proposed to ensure inter-division cooperation in production workshop, based on the interaction of multi-agent systems. The scheme of interaction of the developed software with the existing information systems of the enterprise and the managerial staff of the workshop to provide information and make decisions is formalized.

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