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METHOD AND MEANS FOR THE CREATION OF MULTI-AGENT SYSTEM OF MANAGEMENT AND CONTROL OVER LABOUR RESOURCES ALLOCATION

Method of the labour resources distribution between the process tasks has been developed taking into account employees' performance characterstics and their load level. A new approach with psy-factor consideration to the work efficiency estimation is suggested. Multi-agent system of management and control over labour resources allocation has been realized.

Key words: *labour resources allocation, the efficiency of labour resources allocation, psy-characteristics of the work, labour efficiency, employee's load, agent-oriented approach, multi-agent system.*

Current Importance of the Problem

Current importance of the problem is determined by the growing scale of manufacturing processes and increasing requirements as to the process being completed in proper time through optimal allocation of the recourses according to the process work schedule. Problems of labour resources allocation are related to the complex multi-extreme problems [1-5].

There exist a small number of particular cases of allocation problems for which precise solution procedures were suggested. One of such procedures is Hungarian method applied to the labour resources distribution between the tasks that are not interrelated as to their completion time. Besides, Hungarian method does not take labour resources load into account. Modern systems of labour resources management support the function of labour resources allocation and redistribution in terms of load but the choice of assigning a certain task to a certain employee is still made by the project manager. At the same time it is not always reasonable to rely upon the manager's intuition and experience, especially in case of a novice manager. Therefore, there exist a problem of finding new methods for optimal labour resources allocation that will make it possible to reduce the process completion period by increasing the efficiency of labour resources distribution between the process tasks.

Problem statement

Thus, there exist a problem of increasing the efficiency of labour resources distribution between the process tasks on the basis of the new technology of labour resourses allocation according to the order of process tasks completion with psy-characteristics of the employee's work and his load level being considered.

Solution method for the problem of optimal labour resources allocation.

For solving the stated problem a new technology is suggested for labour resources allocation on the basis of the agent-oriented approach that includes:

A new method of labour resources allocation that, unlike the existing ones (not considering psy-characteristics of the employee's work), enables resources distribution according to the schedule and at the same time allows to take into account psy-factors of the employee's performance and his load, which provides higher optimization level of labour resources allocation.

A new approach to the evaluation of the efficiency of software developer work. This approach, unlike the existing ones, that are based on the work efficiency estimation as the ratio of the work per time unit, allows to consider such characteristics of the employee's performance as speed of response, knowledge level, responsibility and reliability, which improves the accuracy of the employee's work efficiency;

Mathematical model, describing interaction of the agents of labour resources allocation system that, unlike the existing models based on the choice the agent's action according to the available knowledge on the problem and the environment, makes it possible to choose the agent's action taking into account not only knowledge but also to predicts how the action will effect general allocation of the resources, which allows to obtain optimal distribution.

Mathematical model of the system of management and control over labour resources allocation that, unlike the known models oriented towards material resources distribution, allows to take into account the special features of labour resources and makes it possible to automate labour resources allocation and control process.

The essence of the new method of labour resources allocation on the basis of the agent-oriented approach lies in the following: each task and each employee is represented by individual agents. In order to provide interaction of the agents, target functions, sequence in which agents enter into negotiations, the type of interaction are determined.

Depending on the schedule of the process work completion, the sequence in which task agents enter into negotiations is formed. This sequence is defined as an ordered set m of the agents' subsets V_1 and V_k such that all types of work with the agents that belong to the given subset can be performed only after the completion of all the tasks with the agents that belong to the subset having a smaller number.

$$V_k = \{A_{T_i\, i} \in I / P^I_{A_{T_i}} \subseteq \bigcup_{j=1}^{k-1} V_j\} \setminus \bigcup_{j=1}^{k-1} V_j, \;\; k = \overline{2,m}\,, \tag{1}$$

Where A_{T_i} – is operation agent of T_i process, $P^I_{T_i}$ – agents set with the operations that directly precede operation T_i.

While agents from subset V_1 take decision about the strategy choice, they predict reaction of the agents that make decision after them. Such interaction is determined according to Nash equilibrium1 [6]:

$$\begin{aligned} NE_1(S_i, y_{G_i}) = \{ y_{S_i} \in A_{S_i} \big/ \forall j \in S_i\, \forall y_i \in A_j \; f_j(y_{Gi}, y_{S_i}, \psi_i(NE_1(L_i, y_{G_{i+1}}))) \geq \\ \geq f_j(y_{G_i}, y_{Si}\big/ y_j, \psi_i(NE_1(L_i, y_{S_i}\big/ y_j, y_{G_i})))\}, \end{aligned} \tag{2}$$

where $y_{G_m} = (y_i)_{i \in G_m} \in A_{G_m} = \prod_{i \in G_m} A_i$ – actions vector for the agents from set G_m, $y_{S_m} = (y_i)_{i \in S_m} \in A_{S_m} = \prod_{i \in S_m} A_i$ – actions vector for the from set S_m, $y_{S_m} | y_i$ – actions vector for the agents y_{S_m} from set S_m, where actions of the i-th agent are replaced by y_i.

Agents of other subsets choose their behaviour strategies depending on the future choice of other agents. Such interaction is determined from Nash equilibrium 2 [6]:

$$\begin{aligned} NE_2(I \setminus \{i\}, u_i(\cdot)) = \{ y_{I\setminus\{i\}} \in A_{I\setminus\{i\}} \big/ \forall_j \in I \setminus \{i\}\, \forall y_j \in A_j, f_j(y_{I\setminus\{i\}}, u_i(y_{I\setminus\{i\}})) \geq \\ \geq f_j(y_{I\setminus\{i\}}\big/ y_j, u_i(y_{I\setminus\{i\}}\big/ y_j))\}. \end{aligned} \tag{3}$$

In general form agents' interaction is defined by the total of the agents set, the set of their assumed actions and the set of target functions:

$$C = (N, \{D_i\}_{i \in N}, \{f_i(\cdot)\}_{i \in N}), \tag{4}$$

where N – agents set, $\{D_i\}_{i \in N}$ – set of their assumed actions, $\{f_i(\cdot)\}_{i \in N}$ – set of the agent target functions.

Target function of the agent's behaviour depends on the environment of agents' interaction, target function of the agent's class and vector of the actions of all agents:

$$f_i = f_i(f_{c_a}, \theta, d), \tag{5}$$

where f_{c_a} – is target function that is defined by the class of the agent (f_{T_i} or f_{W_j}), θ – state of the environment,

- $d = (d_i, d_{-i}) = (d_1, d_2, ..., d_n) \in D' = \prod_{j \in N} D_j$ – vector of the actions of all agents.

The target function of class tasks is to maximize the efficiency of employee

$$f_{T_i} = \max \sum_{i=1}^{n} \sum_{j=1}^{m} \varepsilon_{W_{j\,T_i}} X_{ij},$$
$$\textit{under condition} \tag{6}$$
$$\sum_{i=1}^{n} X_{ij} = 1,\ \sum_{j=1}^{m} X_{ij} = 1,\ X_{ij} = [0,1].$$

Target function of the class of employees is determined by minimization of the load coefficient

$$f_{W_j} = \min \sum_{i=1}^{n} \sum_{j=1}^{m} k_{load_{W_j}} X_{ij},$$
$$\textit{under condition} \tag{7}$$
$$\sum_{i=1}^{n} X_{ij} = 1,\ \sum_{j=1}^{m} X_{ij} = 1,\ X_{ij} = [0,1].$$

Proceeding from rational behaviour each agent will try to choose the best (in terms of the target function) action for himself under preset conditions. Therefore, the principle of decision taking by the agent as to the action choice will be as follows: he will try to choose the action that will be the most useful for him depending on the state of the environment $\theta \in \Omega$ and actions of other agents [6]:

$$BR_i(\theta, d_{-i}) = Arg \max_{d_i \in D_i} f_i(\theta, d_i, d_{-i}),\ i \in N. \tag{8}$$

For calculation of the work efficiency, that is used as a target function of the class of problem,s a new approach is suggested. Unlike the existing approaches, that are based on the estimation of the work completed in a unit of time, this method allows to consider such psy-characteristics of the employee's work as speed of response, knowledge level, responsibility and reliability. This enables to increase the accuracy of the employee's work efficiency evaluation.

Software development is related to mental activities. That is why the definition of work efficiency as the ratio of the work completed in a unit of time does not fully reflect the complexity of the problem, the amount of knowledge and efforts spent on the fulfillment of the task by a definite employee. It is evident that time spent on the solution of one task by different employees depends on the work experience, employee's qualification, level, knowledge required for problem solution. Besides, work efficiency is also influenced by certain psy-factors: employee's speed of response (depending on the individual temperament), state of health etc. Therefore, for work efficiency estimation we suggest to introduce a definite utility coefficient.

Work efficiency with utility consideration will be defined as the time spent on the completion of work which depends on the utility coefficient value:

$$\varepsilon_{W_j} = \frac{V_{T_i}}{t_{T_i W_j} k_{utility}}, \qquad (9)$$

где V_T – the total work value, $t_{T_i W_j}$ – time spent on the operation completion by the employee, $k_{utility}$ - utility coefficient.

Utility coefficient is a complex coefficient that depends on the speed of response, reliability coefficient, responsibility coefficient and knowledge coefficient.

$$k_{utility} = S_{Wj} k_{knowledge} k_{responsibility} k_{reliability} \qquad (10)$$

where $S_{W_j}(t) = \frac{V_{W_j}}{V_T}$ – employee's speed of response, $k_{knowledge} = \frac{X_1 Z_1 k_1 Tech_1 + X_2 Z_2 k_2 Tech_2 + ... + X_n Z_n k_n Tech_n}{k_1 Tech_1 + k_2 Tech_2 + ... + k_n Tech_n}$ – knowledge coefficient, $k_{responsibility} = [0,1]$ – employee's responsibility coefficient, $k_{reability} = \frac{N_{р.д.} - N_{н.д.}}{N_{р.д.}}$ – к employee's reliability coefficient, $N_{w.d}$ – the number of working days in the given period, $N_{ab.d}$ – the number of days when the employee W_j was absent, Z_n – coefficient that indicates if an employee hast mastered the technology, $Z_n = [0,1]$, $k_n Tech_n$ – the volume of work performed with the help of the technology $Tech_n$, n – number of technologies..

Work efficiency, estimated by this approach, will be more informative because it takes into account psy-characteristics of the employee's performance. The target function of work efficiency maximization with psy-characteristics of the employee's performance being taken into account will enable optimal labour resources distribution between the process tasks.

Using the elaborated method of labour resources distribution and approach to determination of employee efficiency mathematical model of labour resources distribution was elaborated. The model takes into consideration duration of work execution depending on psy – character of its work and level of his load. The given model of resources distribution served as the basis of multiagent system mathematical model of labour resources distribution.

Find the minimum of the target function

$$Z = \sum_{i=1}^{n} \sum_{j=1}^{n} t_{T_{iW_j}} \left| k_{utility_{W_j}} - k_{opt} \right| X_{ij},$$

under condition (11)

$$\sum_{i=1}^{n} X_{ij} = 1, \ \sum_{j=1}^{n} X_{ij} = 1,$$

where $X_{ij} = \begin{cases} 1, \\ 0, \end{cases}$ if j-employee fulfills i- th task

$t_{T_{iW_j}} = \frac{V_{T_i}}{8k_{utility}}$ - time spent on the task T_i by the employee W_j that depends on the psy-characteristics of the employee.

Except the problem of optimal labour resources allocation, multi-agent system of management and control over labour resources allocation had to solve one more problem: to provide the control over resources distribution. This problem was the basis for defining target function of the employee's performance control agent. This function can be presented in the following form:

$$K_n = F < T_q, U, W_{P_k}, N_{\lambda_{P_k}}, A_{\lambda i}(P_k, t), \varepsilon_{\lambda i}(P_k, t), K_{\lambda i}, f_{P_k}(t, d_{P_k}) > \to K_{opt} , \qquad (12),$$

where K_n – employee's criticality coefficient, T_q – data flow volume, U – объем потока данных, W_{P_k} – total number of the projects of the firm, $N_{\lambda_{P_k}}$ – the number of employees engaged in P_k project, $A_{\lambda i}$ – intensity of the individual employee's communication λ_i with other employees within the limits of the project P_k during t period, $\varepsilon_{\lambda i}$ – efficiency of each employee's λ_i work on project P_k during t period t, $K_{\lambda i}$ – utility coefficient for employee λ_i , $f_{P_k}(t, d_{P_k})$ – desirability function as to the project results, d_{P_k} – period of project P_k completion, k – project number.

The task of the agent of control over the employee's activities is to determine the most "critical" employees. If such employees lose the ability to work, it will result in the increased probability of the project not being completed in proper time. For such activities the criticality coefficient is higher than its optimal value.

The developed methods of the resources allocation on the agent basis, mathematical model of resources allocation with the consideration of psy-characteristics and load level of the employee's work, psy-oriented approach to the estimation of the employee's work efficiency have made the basis for the mathematical model of the multi-agent system of management and control over the resources allocation. The model can be represented in the following form:

$$MAS = (S_{sys}, A_{clas}, C_{agent}, ENV, S_{env}, C_{env}, beh_{sys}, beh_{env}, beh_{agent}) , \qquad (13)$$

де $S = \{s, s', s'', ...\}$ – set of all possible states of the system, $A_{clas} = \{A_c, A_{T_i}, A_{W_j}\}$ – set of all possible agent classes of the system, $C_{agent} = \{C_1, C_2, ..., C_n\}$ – set of all possible communications between agents of the system, $ENV = \{E_1, E_2, ..., E_m\}$ – – set of all possible environments of the system, $S_{env} = \{s, s', s'', ...\}$ – set of all possible environments states of the system, C_{env} – set of all possible communications between environments of the system, beh_{sys} – behaviour function of the system, beh_{env} – behaviour function of an environment, beh_{agent} – behaviour function of agents of one class.

Mathematical model of multiagent system has the following form:

$$agent = (S_a, D_a, K_a, G_a, A, K_{na}, SR_i, SR_r, S_{env}, beh_{env}, beh_{agent}, cons) , \qquad (14)$$

де S_a – set of agent states, D_a – set of agent actions, K_a – set of agent knowledge about itself, G_a – set of agent goals, A – set of agents-neighbours, K_{na} – set of knowledge received from agents-neighbours, SR_i – set of knowledge of an ideal state of an employment scheduling, SR_r – set of knowledge of a real state of an employment scheduling, S_{env} – set of environment states, beh_{env} – behaviour function of the environment, beh_{agent} – behaviour function of the agent, $cons$ – condition of achievement to a consensus.

The results obtained from the comparison of the developed method with the existing ones have shown that the Hungarian method does not give the desired results of the labour resources allocation. When this method is used limit for canceling the attraction of additional resources to the project is either violated of project completion terms become considerably longer, which is against customer's wish. Evaluation of the time, required for project completion, has shown that application of the utility coefficient to the resources allocation according to the developed method enables more accurate evaluation of the time spent by a certain employee for the work completion and to choose the best variant. This has made it possible to achieve 11% reduction of project completion time. According to the developed method, the value of daily variations in resources demand is 1,85. Besides, the developed method makes it possible to automate the process of labour resources allocation and the obtained allocation will be the optimal one.

Conclusions

The paper presents a new information technology of labour resources allocation that has made it possible to increase the efficiency of labour resources distribution between the project tasks due to the application of agent-oriented approach, consideration of psy-characteristics of the employee's performance and load level. According to this technology, multi-agent system has been created for management and control over labour resources allocation. The developed system has made it possible: to entrust the process of assigning an employee to a certain work (that formerly was the task of a manager) to the intellectual agents; to avoid reviewing of all the possible assignments of the employees to a certain task by providing negotiations between system agents; to ensure optimal labour resources distribution in accordance with the sequence of tasks completion and employee's load along with the account of psy-characteristics of the employee's performance for the evaluation of time spent on the task. All this allowed to obtain more accurate work schedules and histograms of the labour resources demand.

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