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OPTIMIZATION OF TIME RESOURCE PARAMETERS AND CORPORATE TRAINING RESULTS

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This article proposes a mathematical model for drafting the corporate training time-table which describes the time resource limitations imposed on the said processes and aims at the optimization of the target results. The training process is discussed as being integrated into the key corporate business processes. The employees are grouped into functions, with a set of alternative curricula assigned to each group. Such curricula vary by length, effect on the key competences, quality and cost of business processes. The efficiency of attainment of the educational process goals varies due to the alternative selection of the curricula for various staff groups and distribution of the training events in time.

The formalized mathematical model is a linear programming integer model with a specific block limitation matrix. The parameters of its target functions and limitations are built according to a series of domestic and foreign assessment theories for the corporate training curricula. The optimum solution of the problem is achieved through the branch and bound method and left-hand tree traversal. The structure of the dual problem provides for easy evaluation of vertexes based on the duality theory.

Keywords: curricula, training time resource parameters, training effects, mathematical model, linear programming integer task, branch and bound algorithm.

Introduction

The highly qualified employees are the core intellectual asset of any company today [1]. In any economy developing dynamically, maintenance of high qualification of the staff is only possible due to the effective corporate training and re-skilling management.

The corporate professional studies aim at raising the level of professional competences, mastering the professional technology data, and in-depth understanding of the manufacturing process.

The effective management of continuous training across the entire company or any division thereof is only possible if based on thorough planning of the process in question and detailed evaluation of the results. Any training processes must be integrated into the major manufacturing or managerial cycles of the company to comply with the business development goals [8, 9]. This article proposes a mathematical optimization model and the respective algorithms for building the time-table of corporate staff training. The off-the-job training is discussed; the requisite fulfillment of the current production plan is considered; the dynamic changes of the competence levels and quality of business process completion are analyzed with reference to the timeline parameters and cost of business processes. Training aims at the increased compliance of the staff with the solution of the current and prospective tasks.

Modeling of various aspects of corporate staff training management and ROI assessment in training is discussed in a variety of domestic and foreign studies by F. Andress, W. Hirsch, I. Cochran, A. Alchian, A. Walters, W. Hirschman, M. Titleman, G. Nadler, W. Smith, B. Henderson, W. Morse, W. Eberneth, C. Wayne [1]. Modeling makes it possible to research the efficiency of manufacturing processes impacted by such factors as the “learning curve effect”, “experience curve effect”, “Horndal effect”, “Hawthorne effect”, “learning effect”, “loyalty effect”, “on-the-job training effect” [10].

The directed impact on such factors may raise ROI in human assets [6]. An effective tool of the factor analysis is mathematic modeling studied by C. Arrow, E. Sheshinski, P. Romer, R. Lucas, R. Lundberg, J. de Jong, F. Levy, J. Glover, C. Pegels, N. Vowmer, F. Loventhal, P. Adler, C. Clark, A. Thomas, D. Tovill, J. Carlson, T. Boucher, N. Lamor, D. Raff, P. Temin, E. Hartig, etc. [1].

Some mathematical models in the economics of the continuous corporate staff training planning and management which explicitly take into account the ties between the professional growth and the economic performance are provided in V.P. Morgunov's work [2]. The author introduces the special performance indices for the professional activities of the staff, builds mathematical training models describing the changed results of the professional activities in relation to the time-span of training. The theory of differential equations is used as a model study tool.

The work by D.A. Novikov, S.A. Barkalova, E.V. Galinskaya [3] discusses the game mathematic models of building an effective training management system based on the coordinated management mechanisms.

The factor analysis, mathematic training models, and training performance criteria developed in the above papers are extensively used for building the model proposed herein.

1. Mathematical Model of Corporate Staff Training Timetable Building: Description

Let us proceed to the formalization of the corporate staff training timetable building model. Suppose we have a division which has N employees grouped by functions. The groups have $N_1, N_2,...,N_p$ employees, respectively; and the employees are numbered with reference to the group order $1, 2,...,N_1, N_1+1,...,N_1+N_2,..., N_1+N_2+...+N_{p-1}+1,...,N_1+N_2+...+N_{p-1}+N_p$. Several curricula $k=1,...,K_m, m=1,...,p$ are planned for the employees in each group. Let $g_k^m, k=1,...,K_m, m=1,...,p$ be the duration of the k^{th} curricula for the m^{th} group; $R_k^m, Q_k^m, H_k^m, C_k^m, k=1,...,K_m, m=1,...,p$ be the change (as a percentage of the current value) of the employee's competence, average performance quality, average completion time, and cost of business processes, respectively, resulting from the completion of the k^{th} curriculum for the m^{th} group of employees. The optimization model proposed herein provides the optimum solution to the curriculum selection issue for each employee in each group and to the determination of the training start points. Planning is performed for T periods of time, and each employee is assumed to have completed not more than one curriculum per such period.

Let us consider the model variables

$$z_{ij}^k = \begin{cases} 1, & \text{if program } k \text{ is chosen for employee } i \text{ within period } j, \\ 0, & \text{otherwise,} \end{cases}$$

where $j=1,..,T$ is the number of the planning period, and proceed to the description of the restrictions and target function.

Restriction 1

Not more than one curriculum may be offered to each employee within the planning period:

$$\sum_{j=1}^{T}\sum_{k=1}^{K_i} z_{ij}^k \le 1, \quad i=1,...,N.$$

Before the curriculum starts, the employees possess certain properties: r_i is the level of competence; q_i is the average level of business process completion; t_i is the average time of business process completion; d_{ij} is the average planned number of business processes within the $j=1,..,T$ period. The proposed model considers the average properties of all business processes performed by an employee. A modified model taking into account all business processes imposed on the employees is also possible. One of the model's simplifications is the assumption that the employee's properties change instantly as a result of training to remain steady in absence of any training.

Restriction 2

As a result of the completion of the curricula, the average quality of business process completion in each group of employees must reach a certain boundary value

$$\sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m} \frac{q_i}{N_m}\left(1+\sum_{k=1}^{K_i} Q_k^m \sum_{j=1}^{T} z_{ij}^k\right) \ge \Theta_m, \quad m=1,...,p.$$

Restriction 3

As a result of the completion of the curricula, the average cost of business process completion in each group of employees must reach a certain boundary value

$$\sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m} c_i\left(1-\sum_{k=1}^{K_i} C_k^m \sum_{j=1}^{T} z_{ij}^k\right) \le S_m, \quad m=1,...,p.$$

Restriction 4

During training, the employee interrupts to fulfill his/her regular job, and his/her tasks are imposed on other employees. Training management should be organized to pay not more than 30% of the planned time at the expense of the overtime works:

$$0{,}7\cdot \sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m} c_i \cdot d_{ij} -$$

$$-\sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m}\left(c_i\cdot d_{ij}\left(1-\sum_{t=1}^{j}\sum_{k=1}^{K_i} z_{it}^k\right)+\sum_{k=1}^{K_i} c_i\left(1-C_k^m\right)\cdot d_{ij}\left(1-\sum_{t=T}^{j-g_i^k+1} z_{it}^k\right)\right)\le 0.$$

Restriction 5

The company has a separate asset pool M used to fund training. The cost of all training curricula for all employees may not be more than the funds within such pool:

$$\sum_{i=1}^{N}\sum_{j=1}^{T}\sum_{k=1}^{K_i} C_i^k z_{ij}^k \le M.$$

The maximization of employee competence is deemed the *target function* of the model

$$\sum_{i=1}^{N} r_i\left(1+\sum_{k=1}^{K_i} R_i^k \sum_{j=1}^{T} z_{ij}^k\right)\to \max.$$

Based on the resulting target function and restrictions, the model for corporate staff training timetable building takes the form of

$$\sum_{i=1}^{N} r_i\left(1+\sum_{k=1}^{K_i} R_i^k \sum_{j=1}^{T} z_{ij}^k\right)\to \max$$

$$\sum_{j=1}^{T}\sum_{k=1}^{K_i} z_{ij}^k \le 1, \quad i=1,...,N$$

$$\sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m} \frac{q_i}{N_m}\left(\sum_{k=1}^{K_i} Q_k^m \sum_{j=1}^{T} z_{ij}^k\right) \ge \Theta_m - \sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m} \frac{q_i}{N_m}, \quad m=1,...,p$$

$$\sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m} \frac{c_i}{N_m}\left(\sum_{k=1}^{K_i} C_k^m \sum_{j=1}^{T} z_{ij}^k\right) \ge S_m + \sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m} \frac{c_i}{N_m}, \quad m=1,...,p$$

$$\sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m}\left(c_i\cdot d_{ij}\left(1-\sum_{t=1}^{j}\sum_{k=1}^{K_i} z_{it}^k\right)+\sum_{k=1}^{K_i} c_i\left(1-C_k^m\right)\cdot d_{ij}\left(1-\sum_{t=T}^{j-g_i^k+1} z_{it}^k\right)\right)\ge 0{,}7\cdot \sum_{i=N_1+...+N_{m-1}+1}^{N_1+...+N_{m-1}+N_m} c_i\cdot d_{ij}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{T}\sum_{k=1}^{K_i} C_i^k z_{ij}^k \le M$$

$$z_{ij}^k=\{0,1\}, \quad i=1,...,N, \quad j=1,...,T, \quad k=1,...,K_i.$$

The formalized model refers to the linear programming integer task with Boolean variables. The target is set to find the maximum values of $z_{ij}^k=\{0,1\}$, $i=1,...,N$, $j=1,...,T$, $k=1,...,K_i$ which provide the maximum overall employee competence after the completion of the training curricula [4, 5]. The branch and bound algorithm is suggested as the method of solving the resulting linear programming integer task.

The structure of the linear programming task may be represented as Table. The rows refer to the model variables. The variables are ordered depending on nesting – group order (order of employees in the groups (order of planning periods (order of employee curricula))). The structure of the restriction coefficients reflects has a modular nature.

Model Restriction Structure

1st group																pth group															restrict. type	bin. variable
1st							.	N_1th							.	$N_1+…+N_{p-1}$th							.	$N_1+…+N_p = N$th								
period 1			.	period T			.	period 1			.	period T			.	period 1			.	period T			.	period 1			.	period T				
pr 1		pr K_1	.	pr 1	.	pr K_1	.				.				.				.				.				.	pr 1		pr K_p		
																															≤	y_1
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	≤	
																															≤	y_{N_1}
																															≤	y_{N_1+1}
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	≤	.
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																															≤	y_N
																															≥	v_1
																															≥	w_1
																															≥	g_1
																															≥	v_2
																															≥	w_2
																															≥	g_2
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	≥	.
																															≥	v_p
																															≥	w_p
																															≥	g_p
																															≤	h

2. Branch and Bound Algorithm for the Model of Corporate Staff Training Timetable Building

Let us dwell upon the major aspects of the branch and bound algorithm with reference to the resulting model, i.e. the type of multiway branching and the type of assessment task building.

Multiway branching is performed with regards to the values of the variables $z_{ij}^{k} = \{0,1\}$, $i = 1,...,N$, $j = 1,...,T$, $k = 1,...,K_i$. The first branching relies on the value of variable z_{11}^{1}. When any vertex branches, the left branch matches the value $z_{ij}^{k} = 1$, whilst the right branch matches $z_{ij}^{k} = 0$, respectively. The choice of value $z_{ij}^{k} = 1$ on the left branch considerably decreases the problem order since, due to such choice, all variables automatically go $z_{sp}^{l} = 0, \forall s = i, p \neq j, l \neq k$. The choice of $z_{ij}^{k} = 0$ on the right branch only decreases the problem order by a single variable. The solution of the problem relies on the left-hand tree traversal.

The paper builds the dual problem for assessing the vertexes. The dual problem for the top vertex takes the following form:

$$\sum_{j=1}^{n} y_j + b_1 v_1 + \sum_{m=1}^{p} \left(b_m v_m + d_m w_m + c_m g_m \right) + \text{sh} \to \min$$

$$a_{11} y_1 + a_{(N+1)1} v_1 + a_{(N+2)1} w_1 + a_{(N+3)1} g_1 + a_{(N+3p+1)1} h \ge r_{11}$$

…………

$$a_{1K_1} y_1 + a_{(N+1)K_1} v_1 + a_{(N+2)K_1} w_1 + a_{(N+3)K_1} g_1 + a_{(N+3p+1)K_1} h \ge r_{1K_1}$$

…………

$$a_{1(TK_1)} y_1 + a_{(N+1)(TK_1)} v_1 + a_{(N+2)(TK_1)} w_1 + a_{(N+3)(TK_1)} g_1 + a_{(N+3p+1)(TK_1)} h \ge r_{1K_1}$$

…………

$$a_{(N_1)((TK_1)(N_1-1)+1)} y_{N_1} + a_{(N+1)((TK_1)(N_1-1)+1)} v_1 + a_{(N+2)((TK_1)(N_1-1)+1)} w_1 + a_{(N+3)((TK_1)(N_1-1)+1)} g_1 +$$

$$+ a_{(N+3p+1)((TK_1)(N_1-1)+1)} h \ge r_{N_1 1}$$

………….

$$a_{(N_1)((TK_1)(N_1))} y_{N_1} + a_{(N+1)((TK_1)(N_1))} v_1 + a_{(N+2)((TK_1)(N_1))} w_1 + a_{(N+3)((TK_1)(N_1))} g_1 +$$

$$+ a_{(N+3p+1)((TK_1)(N_1))} h \ge r_{N_1 K_1}$$

……………

$$a_{(N)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_{p=1})(N_{p-1})+1\right)} y_N + a_{(N+3p-2)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_{p=1})(N_{p-1})+1\right)} v_p$$

$$+ a_{(N+3p-1)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_{p=1})(N_{p-1})+1\right)} w_p +$$

$$+ a_{(N+3p)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_{p=1})(N_{p-1})+1\right)} g_p +$$

$$+ a_{(N+3p+1)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_{p=1})(N_{p-1})+1\right)} h \ge r_{N1}$$

………….

$$a_{(N)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_p)(N_p)\right)} y_N + a_{(N+3p-2)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_p)(N_p)\right)} v_p$$

$$+ a_{(N+3p-1)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_p)(N_p)\right)} w_p +$$

$$+ a_{(N+3p)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_p)(N_p)\right)} g_p +$$

$$+ a_{(N+3p+1)\left((TK_1)(N_1)+(TK_2)(N_2)+\ldots(TK_p)(N_p)\right)} h \ge r_{NK_p}$$

$$y_1, \ldots, y_N \ge 0;\ v_m, w_m, g_m \le 0,\ m = 1,.., p;\ h \ge 0$$

The dual problem structure provides for easy finding of a series of admissible points. The examples of such admissible points are

$$y_1 = \max\left\{ \frac{r_{11}}{a_{11}}, \ldots, \frac{r_{1K_1}}{a_{1K_1}}, \ldots, \frac{r_{1K_1}}{a_{TK_1}} \right\}, y_2 = 0, \ldots, y_N = 0;\ v_m, w_m, g_m = 0,\ m = 1,.., p;\ h = 0$$

……….

$$y_1 = 0, \ldots, y_N = \max\left\{ \frac{r_{N1}}{a_{N\left((TK_1)(N_1)+\ldots+(TK_{p-1})(N_{p-1})+1\right)}}, \ldots, \frac{r_{NK_p}}{a_{N\left((TK_1)(N_1)+\ldots+(TK_p)(N_p)\right)}} \right\};$$

$$v_m, w_m, g_m = 0,\ m = 1,.., p;\ h = 0.$$

The admissible points can be similarly found on the basis of the nonzero variable pairs, e.g.:

$\left(y_j > 0, v_1 < 0, \forall j = 1, \ldots, N_1 \right)$, $\left(y_j > 0, w_1 < 0, \forall j = 1, \ldots, N_1 \right)$,

$\left(y_j > 0, g_1 < 0, \forall j = 1, \ldots, N_1 \right)$, …, $\left(y_j > 0, v_p < 0, \forall j = N_1 + \ldots + N_{p-1} + 1, \ldots, N \right)$,

$\left(y_j > 0, w_p < 0, \forall j = N_1 + \ldots + N_{p-1} + 1, \ldots, N \right)$,

$\left(y_j > 0, g_p < 0, \forall j = N_1 + \ldots + N_{p-1} + 1, \ldots, N \right)$.

The admissible options are also built on the condition that
$y_1,...,y_N = 0; v_m, w_m, g_m = 0, m = 1,.., p; h > 0$.

For the calculation of the target function values of the dual problem within the resulting individual options, the assessment of the initial problem target function is built.

The genetic algorithms may be also used for solving the resulting linear programming integer task [7].

Conclusion

The training and competence development curricula are the integral part of the staff development management in today's companies. The economic and social effectiveness of such curricula relies on a series of factors (choice of the curricula, correct formulation of the goals and targets, individual readiness assessments for the completion of the curricula, curriculum planning) and is assessed on the basis of the models overviewed in the Introduction hereto. This paper describes the mathematical optimization model and the respective algorithms for the task of building the timetable and selecting the alternative curricula in the corporate training tasks, which enables the formalization of some aspects intrinsic to the said classical models in the language of mathematics.

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ОПТИМИЗАЦИЯ РЕСУРСНО-ВРЕМЕННЫХ ПАРАМЕТРОВ И РЕЗУЛЬТАТОВ ПРОЦЕССА КОРПОРАТИВНОГО ОБУЧЕНИЯ ПЕРСОНАЛА

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Предложена математическая модель составления расписания процесса корпоративного обучения персонала, описывающая ресурсно-временные ограничения реализации данного процесса и направленная на оптимизацию целевых результатов обучения. Рассматривается процесс обучения, встроенный в основные бизнес-процессы компании. Предполагается деление сотрудников на однородные по функциональным обязанностям группы, для каждой группы предусматривается множество альтернативных программ обучения. Программы отличаются длительностью, степенью влияния на основные компетенции, качество и стоимость выполнения бизнес процессов. Эффективность достижения целей процесса обучения варьируется за счет альтернативного выбора образовательных программ для различных групп сотрудников и распределения мероприятий обучения во времени.

Формализовано предложенная математическая модель является моделью целочисленного линейного программирования со специфической блочной матрицей ограничений. Формирование параметров ее целевой функции и ограничений опирается на ряд известных российских и зарубежных теорий оценки эффективности программ корпоративного обучения. Для нахождения оптимального решения задачи используется метод ветвей и границ с левосторонним обходом дерева. Структура двойственной задачи позволяет легко получать оценки вершин на основании теории двойственности.

Ключевые слова: программы обучения, ресурсно-временные параметры обучения, эффекты обучения, математическая модель, целочисленная задача линейного программирования, метод ветвей и границ.

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