A Mathematical Job Allocation Model to Maximize Career Development Opportunities for Construction Workers

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Abstract

The job allocation models used in construction projects have been designed mainly to meet the objectives of the employers such as maximizing productivity and tended to pay inadequate attention to meet the needs and objectives of construction workers. Meeting the objectives of workers, however, is a basic component of corporate social responsibility and vital to improve job satisfaction among construction workers. Among various items on wish-list of workers, availability of career development opportunities in projects stands out as a key factor affected considerably by job allocation decisions. This paper presents an innovative mathematical model for optimization of task allocation in construction projects to maximize the availability of career development opportunities to individual construction workers, paving the way for their career development. A Euclidean distance function in n-space is specified as objective function of career development which measures and compares the distance between ideal skill levels of employees to initial skill levels and developed ones after job allocation. The proposed model is applied to an illustrative case project involving the allocation of tasks to workers with different skill levels in a construction contractor company. Results show a successful task allocation which has contributed to workers' occupational development and made them closer to their ideal skill level.

Keywords

Construction Industry; Career Development; Mathematical Model of Job Allocation; Corporate Social Responsibility

1 Introduction

The construction industry is one of the extensive global employment sectors which provides career opportunities for a noticeable percentage of the labour market and contributes to a substantial share of the world's gross domestic product (GDP) [1]. As a result, construction industry is acknowledged widely as a fundamental driver of national productivity in most developed and developing countries; and therefore improving the productivity of construction industry through workforce planning has been a major focus of research over the past several decades [2, 3]. Numerous novel conceptual and mathematical workforce planning techniques have been developed to improve the productivity of workers through optimizing the hiring and firing decisions [4], multiskilling strategy [5], training of existing workers [6], optimization of crew composition [7], and optimizing the job allocation [8]. However, while meeting the productivity objectives is crucial, placing the focus solely on productivity and other financial objectives of the employers, has led to a significant level of ignorance with regards to effects that job allocation decisions may have on main players in construction projects, i.e. the workers [1]. One of the direct effects of job allocation decisions on workers is related to amount of career development opportunities made available to them through allocated jobs [9].

Accordingly, job allocation planning provides an opportunity to maximize the availability of career development opportunities for the workers. However, to the best of our knowledge, there is currently a lack of a systematic method to account for career development opportunities in optimizing the task allocation in construction projects. The existing literature on career development opportunities in task allocation to workers is mainly limited to (1) qualitative models of career interests, choice, and development [10-12], and (2) theoretical propositions such as psychological theory of work adjustment [13], and social learning theory of Career Decision Making (CDM) [14]. In the present paper, an innovative mathematical model for optimization of task allocation to maximize career development opportunities available to construction workers is proposed. The proposed model is applied to and solved for an illustrative case project involving the allocation of tasks to workers with different skill levels in a construction contractor company.

2 Mathematical Model Formulation

The model proposed in this study aims at solving the problem of job allocation among available personnel with the objective of maximizing the career development opportunities available to workers. It is assumed that employees begin their career from entry level and promotions to higher levels are based on achieving the experience requirements for different skills required for the level. In addition, it is assumed that the amount and breakdown of the work to be performed, number of available labour forces along with their skills and proficiencies, and their historical learning rates are known or have been previously measured. The objective is to distribute the given workload among individual workers in a way that a majority of workers take a step forward in meeting the skill experience requirements for promotion to the next career level.

2.1 Terminology and Notation

We denote I as the set of primary skills of workers. For instance, if the skillsets required in a building operation include reinforcement iron-working, carpentry, and concrete pouring, these three primary skills are elements of the set I.

The skill level of the worker is denoted by set E. Five stages of skill development is presumed based on the modelling of human expertise suggested by Dreyfus [15]. Description of the abilities and requirements of each skill level are explained in 'Table 1'. Skill level acquisition is mainly assumed by years' experience. First skill level i.e. $\mathrm{e} = 1$ indicates a novice worker (0–3 years of experience), $\mathrm{e} = 2$ represents a beginner worker (3-7 years of experience), $\mathrm{e} = 3$ denotes a competent one (7-15 years of experience), $\mathrm{e} = 4$ indicates a worker with proficient skill level (15-22 years of experience), and $\mathrm{e} = 5$ indicates an expert worker (22-30 years of experience).

The type of the activity is denoted by set J; e.g. values of $j = 1, 2, 3$ may be assigned when working on columns, beams, and slabs, respectively. In the classification adopted by this study, each activity is comprised of several tasks which are denoted by set M. It is worth mentioning that task $m \epsilon M$ corresponds to one or more required skill(s) $i \epsilon I$.

2.2 Decision Variables and Objective Function

The objective targeted in this study is to maximize the personnel's career development opportunities. The decision variables are the amount of work allocated to each worker in each skill (y_k^i). Based on literature, we assume that promotion of each individual worker to the next career level is achieved through improving his experience in required skills to the minimum level of experience required by the next level position [12]. The enhancement in skill level of individual k in skill i due to performing the allocated job (y_k^i) is formulated by the equation below:

$$S_{ik} = \dot{S}_{ik} + \alpha_{ik} \times y_k^i \tag{1}$$

Where $\dot{S}_{ik}$ is the initial level of experience of individual k in skill i, y_k^i is amount of work related to skill i which is allocated to individual k, α_{ik} is a coefficient obtained from learning rate of individual k in skill i, and S_{ik} is the improved skill level of individual k in skill i after performing the allocated task.

We assume that each employee has a particular goal in terms of desired job and level in the organizational hierarchy, which we herein define as the ideal job for the candidate. According to Parsons [16], employee's active involvement in selecting their career instead of letting chance to operate in looking for a job, may lead to considerable increase in their job satisfaction and efficiency as well as a decrease in employers' costs. The ideal job for each candidate can be determined based on candidate's desired job or best fit based on various psychological character analyses methods. We assume that the key requirement to qualify for the ideal job is to achieve the required skill levels for the job which can be identified from Human Resource (HR) data and qualification of current/previous individual holding such positions. In this study, parameter $\ddot{S}_{ik}$ is defined to represent skill level associated with the ideal job for candidate k. The current skill levels of worker and those associated with the ideal job of the workers are defined by vectors presented in equations (2) and (3), respectively.

$$\dot{S}_{ik} = (\dot{S}_{1k}, \dot{S}_{2k}, \dots, \dot{S}_{ik}) \tag{2}$$

$$\ddot{S}_{ik} = (\ddot{S}_{1k}, \ddot{S}_{2k}, \dots, \ddot{S}_{ik}) \tag{3}$$

A value of zero for the level of a particular skill is possible and means no experience in that particular skill. A Euclidean distance function in n-space, E^n, is defined to quantify the distance between the current level of skills and the ideal level of skills as defined by equation (4). The distance of each individual k from its ideal job is therefore defined as:

$$D_k = \sqrt{(\ddot{S}_{1k} - S_{1k})^2 + (\ddot{S}_{2k} - S_{2k})^2 + \cdots + (\ddot{S}_{ik} - S_{ik})^2} \tag{4}$$

Accordingly, to maximize the career development opportunities for each worker, the objective function is defined as follows:

$$\text{minimize } max_{\{k \in K\}} D_k \tag{5}$$

Table 1 Different skill levels and their descriptions

Skill level, E	Title of skill level	Description
1	Novice	The worker can assist other experienced workers, and transfer goods.
2	Beginner	The worker can work independently on simple tasks under supervision of a senior worker.
3	Competent	The worker can perform all simple and complicated tasks within his skill range.
4	Proficient	The worker can perform all tasks, within his skill range, quickly and with minimum deficiencies.
5	Expert	In addition to performing all tasks, within his skill range, the worker can supervise other workers.

2.3 Constraints

The constraints considered in this model are presented by equations (6) to (8). Constraint (1) sets the total amount of work allocated to personnel to be equal to the total amount of work available in the project for the entire crew in a particular trade. Judgments of fairness include four distinctive types of perceptions. Distributive justice perception adopted in this study aims at ensuring fair distribution of hiring, promotion, and workload allocation over individuals [17]. Constraints (2) and (3) are defined to account for distributive justice. Constraint (2) ensures that the maximum working hours per week for each worker does not exceed the specified limit value (U_k). Constraint (3) ensures a minimum weekly number of allocated hours of work (L_k) to each worker. In these two constraints, w is total number of weeks in lifespan of the project.

$$Constraint\ (1):\quad \sum_{k=0}^{K} y_k^i = H_k \quad ,\forall i \in I \qquad (6)$$

$$Constraint\ (2):\quad {y_k^c}/_{w} \le U_k \quad ,\forall k \in K \qquad (7)$$

$$Constraint\ (3):\quad {y_k^c}/_{w} \ge L_k \quad ,\forall k \in K \qquad (8)$$

3 Case Study; Results, and Discussion

The illustrative case study considered in this paper involves allocating the tasks in a construction operation to a crew of ten personnel (P_1 to P_{10}). The activity involves three different tasks characterized by six different skill types, presented by S_1 to S_6, with five competency skill levels considered for each skill type. The initial and ideal level at each skill are known for all workers and presented in ‘Table 2’. Upper and lower bound of weekly workload of each individual worker are considered as 10 and 60 hours, respectively. COUENNE, an open source code for solving global optimization problems [18], was selected to solve the problems within AMPL framework. Two different scenarios are considered to evaluate the effectiveness of our model in maximizing the career development opportunity as characterized by the distance of each worker to its ideal skill set. In the first scenario our proposed model is used to allocate the tasks, while in the second scenario the tasks are allocated by applying the conventional productivity maximization job allocation approach [8]. The outcome which includes developed skill levels for all employees after job allocation, allocated hours to personnel, and final distances (the distance between developed and ideal skill levels) are presented for both scenarios below.

Table 2 Initial, ideal, and newly developed skill levels along with allocated hours at each skill type

Personnel	Skill	Initial skill level	Ideal skill level	Developed skill level		Allocated hours (y_k^i)	
				Scenario 1	Scenario 2	Scenario 1	Scenario 2
Bob Johnston (P_1)	Carpentry (S_1)	3	5	3.12	3	38	0
	Concreting (S_2)	4	5	4.06	4	31	0
	Electrician (S_3)	2	5	2	2	0	0
	Form working (S_4)	1	3	1.19	1	49	0
	Plastering (S_5)	4	5	4	4	0	0
	Reinforcement (S_6)	0	3	0.24	0.48	120	240

George Fine (P_2)	Carpentry	0	3	0	0	0	0
	Concreting	3	4	3	3	0	0
	Electrician	3	5	3.60	3	201	0
	Form working	2	4	2.06	2.48	32	240
	Plastering	1	5	1.02	1	6	0
	Reinforcement	1	3	1	1	0	0
Jerry Jones (P_3)	Carpentry	2	4	2.05	2	25	0
	Concreting	3	5	3.07	3	33	0
	Electrician	3	4	3	3	0	0
	Form working	1	4	1.10	1	52	0
	Plastering	2	4	2	2	0	0
	Reinforcement	0	3	0.26	0.48	128	240
John Rossi (P_4)	Carpentry	2	4	2.08	2.48	39	240
	Concreting	1	2	1.03	1	32	0
	Electrician	2	4	2	2	0	0
	Form working	1	4	1.15	1	50	0
	Plastering	2	4	2	2	0	0
	Reinforcement	0	3	0.12	0	118	0
Martin Davidson (P_5)	Carpentry	0	3	0.11	0	38	0
	Concreting	2	4	2.06	2.29	32	145
	Electrician	4	5	4	4.67	0	170
	Form working	4	5	4.19	4	49	0
	Plastering	3	5	3	3	0	0
	Reinforcement	2	4	2.24	2.54	121	270
Michael McCray (P_6)	Carpentry	0	1	0.08	0.15	39	76
	Concreting	3	3	3.03	3	32	0
	Electrician	3	5	3	3	0	0
	Form working	3	5	3.15	3	49	0
	Plastering	0	3	0	0.33	0	164
	Reinforcement	1	3	1.12	1	119	0
Mike Parks (P_7)	Carpentry	1	5	1.18	1	181	0
	Concreting	2	4	2.09	2	45	0
	Electrician	2	4	2.66	2	222	0
	Form working	1	3	1.09	1.64	45	320
	Plastering	0	4	1.19	0	397	0
	Reinforcement	0	2	0	0	0	0
Nick Lewis (P_8)	Carpentry	0	4	0.12	0.38	40	127
	Concreting	2	4	2.06	2.28	32	142
	Electrician	4	5	4	4.65	0	163
	Form working	4	5	4.19	4	48	0
	Plastering	3	5	3	3	0	0
	Reinforcement	2	4	2.23	2.19	119	95
Steve Gill (P_9)	Carpentry	2	4	2.08	2	40	0
	Concreting	1	3	1.03	1	32	0
	Electrician	2	5	2	2	0	0
	Form working	1	3	1.15	1	49	0
	Plastering	2	4	2	2.48	0	240
	Reinforcement	0	2	0.12	0	118	0
Tom Peterson (P_{10})	Carpentry	0	3	0	0	0	0
	Concreting	1	4	1.27	1.23	135	118
	Electrician	3	5	3.09	3.36	31	122
	Form working	2	5	2.27	2	135	0
	Plastering	3	5	3	3	0	0
	Reinforcement	1	3	1	1	0	0

Table 3 Initial and final distances for personnel

Personnel	Initial Distance	Final Distance	
		Scenario 1	Scenario 2
Bob Johnston (P_1)	5.29	5.03	5.03
George Fine (P_2)	6.16	5.96	6.02
Jerry Jones (P_3)	5.57	5.32	5.32
John Rossi (P_4)	5.57	5.39	5.41
Martin Davidson (P_5)	4.79	4.56	4.38
Michael McCray (P_6)	4.69	4.56	4.45
Mike Parks (P_7)	6.93	5.96	6.77
Nick Lewis (P_8)	5.48	5.25	4.94
Steve Gill (P_9)	5.38	5.24	5.22
Tom Peterson (P_{10})	6.24	5.96	6.02

In first scenario job allocation has been performed more uniformly and evenly leading to a wide-ranging and comprehensive skill development of all employees. As it can be seen in ‘Table 2’, in our model, all employees have received a certain amount of hourly job in at least three skill type and most of them have developed their skill levels for almost all of skill types. On the contrary, in second model, majority of personnel have been allocated a large amount of job in just one skill type leading to overdevelopment of one skill whereas keeping the rest undeveloped.

Results from ‘Table 3’ indicate all employees have become closer to their ideal skill level after job allocation. However, some subtleties reveal when comparing the final distances derived from two scenarios. Maximum final distances in first and second scenarios for all personnel are 5.96 and 6.77 , respectively, while there is a similar maximum initial distance of 6.93 for both cases. This small change from 6.77 to 6.93 in second scenario, emphasizes the argument that conventional productivity oriented approach does not consider the employee’s perspective objectives e.g. career development into optimization planning. In contrast, results of our model indicate a noticeable contribution to career development of employees and their closeness to ideal skillset (%13.9 for ‘P_7’ and %4.8 on average). Another important advantage of our model is concentration on career improvement of critical employees with longest initial distances to make sure final distance for none of organization personnel does not exceed a threshold value. On the other hand, second model has unnecessarily reduces the distance for employees such as Martin Davidson (P_5) and Michael McCray (P_6) whilst there were people with higher priority for job allocation such as Mike Parks (P_7) and Tom Peterson (P_{10}).

4 Conclusion

In this paper, an innovative job allocation optimization model was presented to maximize the career development opportunities available to the construction workers. Maximizing the career development opportunities available to workers through a systematic workforce planning may lead to considerable increase in job satisfaction of workers and attractiveness of construction industry to skilled workers. The results of the case study presented in this paper showed that implementing our proposed model compared to the conventional productivity oriented model results in a significant improvement in the career development of workers in general and %13.9 advancement in workers’ closeness to their ideal skill set in critical employees. In addition, the proposed model allocates the available jobs more uniformly leading to multi-dimensional skill development of employees whereas in the other model, most of personnel have been allocated a large amount of job in just one skill type leading to overdevelopment of one skill while keeping the rest undeveloped. For future studies, work on more complex problems consisting of various construction trades with personnel from different departments within an organization is suggested. In addition, more constraints reflecting time specific and site specific limitations and regulatory conditions can be considered into modelling.

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