IEEE *Access*
Multidisciplinary : Rapid Review : Open Access Journal

A Decision Model for Human Resource Allocation in Project Management of Software Development (January 2020)

Hui Yi Chiang, Bertrand M.T. Lin

Institute of Information Management, National Chiao Tung University, Hsinchu 300, Taiwan

Corresponding author: Hui Yi Chiang (e-mail: joeyhychiang@gmail.com).

ABSTRACT In project management, especially of software development, human resource allocation is critical not only for project success including timely delivery and products quality but also for cost estimation to a software company to decide to contract projects or not. Many approaches have been proposed to provide assistance for human resource allocation in view of minimizing project duration and project cost or maximizing revenue and efficiency. These approaches may sometimes not be comprehensive in real-world environments without addressing some key factors like transferring cost, communication, and negative efficiency, which usually have crucial impacts on assignment applicability. This article is proposing a framework for assisting a software company to evaluate existing resource for making decisions on whether the estimation of the tender is feasible, and assisting to make human resource allocation for team formation in fixed project duration with labor skill and budget constraint. Within consideration of both the cost and the efficiency, the performance is maximized to verges on the customers' expectations in software development project management on the basis of a real case. Before forming a team for a specific project with well-defined periods and numbers of people with different project roles, the values of key factors in the framework are calculated with individual foundation of computation. We formulate the decision process in integer programming models, and a simulation study is conducted to demonstrate the applicability of the proposed model to assist the decision making process of software companies for team formation. The results of four variants for maximum skill efficiency or minimum hiring cost are illustrated with different considerations of both key factors are included or not proposed in this paper, and demonstrate that these factors could bring out different sources to help companies in making further evaluations for allocating staff in a software development project.

INDEX TERMS Project management; Human resource allocation; Team formation; Software project; Integer programming

I. INTRODUCTION

The triangle constraints suggested in Project Management Body of Knowledge (PMBOK) include time, cost, and scope. These three factors are strongly connected to each other and are used to analyze the quality of work in a project [17, 33, 40]. In general, each triangle constraint must be considered for its balance in the estimate before contracting software development projects [34, 37, 42]. Human resource allocation is a critical social problem not only for project success including delivery on time and products quality but also for cost estimation to a software company to decide to contract projects or not because projects are typically very labor

intensive [8], and it is not uncommon for labor costs on a project to account for 30-50% of the total project costs [51]. In the life cycle of a project, the team is defined and formed in the initiation phase, for the purpose of reducing labor costs, additionally, increasing productivity, quality, and continuity of work [33, 45], and meeting the different and various skill requirements in each phase of project from kicking off to on production preparation, multiskilling is indicated to be a workforce strategy, the workers who can vary according to each project are assigned to be the individuals who actively work on one or more phases according to their knowledge, capabilities, and experience by the foreman [28], and is

commonly implemented in software development projects duration which is executed by regular workers in a software company.

In contemporary software development, assigning the appropriate roles to software practitioners is critical and has become a central issue for improving the quality of software processes. The generalized assignment problem (GAP) comprised of project scheduling, resource allocation, and job assignment [14, 53] is essential because the regular workers must be allocated efficiently and effectively to phases in software development process model in order to accomplish a software development project on time and fulfill customers' requirements subject to limited budget and finite human resources. For project management, a software project manager is required to allocate and schedule one or more developers to each task, whereas in other cases, tasks are distributed to already predefined teams of developers. There have been many approaches proposed to help human resource scheduling and allocation with the model based on triangle constraints, for example, with consideration of minimizing project duration, minimizing project cost, maximizing revenue or maximizing efficiency [23]. However, the triangle is not always sufficient in real-world environment to a project success because some crucial dimensions of success including impact on the project team members, such as their satisfaction with the positions in projects, communication, and collaboration ability with others are omitted [22]. Therefore, the team formation problem which is started in the human resource management domain is extensively studied in many fields, such as operations research, some factors were considered in previous research about social network-based team formation, for example, communication cost [38, 52], team leader [35], online multiple tasks [2], number of skilled experts, capacity on experts [7], and personal cost [36]. In real cases, more than one expert with some skills is demanded for a specific task when composing a team with the consideration of not only skill requirement, but also the negative propagation effects to the efficiency of next tasks in a project; hence, managers have to pay more attention to how to work as a collective unit while analyzing the collaboration and communication ability that will directly influence the collaborative work performance of the team members [22, 48].

For most cases in project management, personnel and task assignment is a practical issue highly related to project duration, cost, scope also meaning customers' expectation, the success of a project, and even the competitiveness of a software company. Subject to the limitation of budget and requirements of various roles in the software development process models of a project, assigning regular workers to roles according to their capabilities and the capabilities demanded by the role to maximize the performance to verge on customers' expectation is one of the most challenging issues. In reality, it is however difficult to achieve optimality in human resource allocation, not only because the variable efficiency and quality of the same staff assigned to different

skills or period, but also the key factors in software development projects and ignored in most of the researches of human resource allocation and team formation, such as communication efficiency, transferring time, and negative efficiency which occurs when someone is assigned to a skill not fully applicably.

The objective of this paper is to propose a combinatorial optimization framework with human resource allocation and team formation which assists the company to make decisions whether the estimation of the tender is feasible based on existing resources, and in assignment with resource constraints and duration, or to improve efficiency and effectiveness in the development period by forming a project team with this model.

The rest of this paper is organized as follows: Section II reviews the literature of human resource allocation, team formation, and communication efficiency; Section III illustrates the proposed model and formulations. The computational experiments based on a real case are described in Section IV, and the calculated results are analyzed and discussed in Section V. Conclusions and suggestions for future research are given in Section VI.

II. LITERATURE REVIEW

A. HUMAN RESOURCE ALLOCATION AND TEAM FORMATION

Human resource allocation problem is a central issue in economic activities. To get the right people to do the right job at the right time can be detrimental to the success of a software project [23]. For project management, in some cases, a software project manager is required to allocate and schedule one or more developers to each task, whereas in other cases, tasks are distributed to already predefined teams of developers. There have been many approaches proposed to help human resource scheduling and allocation with different objectives consideration, such as minimizing project duration, minimizing project cost, maximizing revenue, minimizing risk of delay, or maximizing efficiency demonstrated with different techniques including linear programming, probabilistic modeling, queuing theory, constraint satisfaction, or evolutionary algorithms [23].

Team formation was started in the human resource management domain initially, and becomes important in social network. The team formation problem is first considered in the presence of a social network of individuals and has known to be computationally intractable by [52], who attempted to exploit the collaboration social network with the communication costs between the members to organize a team for a given task [20]. Team formation is ubiquitous in practice, for example, product development teams formed from marketing, engineering, and finance skills, and software development team formed from programmers and software engineers with needed programming and systems skills. It is

also extensively studied in many fields, such as operations research, some factors were considered in previous research about social network-based team formation, for example, communication cost, team leader, online multiple tasks, number of skilled experts, capacity on experts, and personal cost [2, 7, 35, 36, 38, 52]. The generally used methods to form a team are random assignment, self-selection and facilitator assignment. Sorkhi et al. [38] compose teams of experts who have diverse levels of skillfulness by minimizing the communication cost. In the model of [26], the team formation problem is formulated as an integer programming problem aimed at finding an optimal match between individuals and requirements. Majumder et al. [7] impose the capacity constraints which ensure that no experts are assigned tasks beyond the capacity values in the team formation problem. Li et al. [13] proposed methods to condense experts in the collaborative social network to a group graph structure based on the required skills that been satisfied with specified numbers by connecting experts based on the group roles of individuals.

As this review has shown, many studies are proposed with numerous ways to provide assistants for minimizing project duration, minimizing project cost, maximizing revenue, or maximizing efficiency in the literature to deal with human resource allocation and team formation problems: Barreto et al. [3] propose genetic algorithm approaches for resource allocation of a software project including project activities and human resources available, but the task scheduling was not considered; Chang et al. [11] investigate a scheduling model using genetic algorithm to be a viable tool to help guide project manager in daily routines, but continuity of allocation is not included; Chang et al. [10] design a methodology called software project management net to develop and estimate the schedules and budgets using task precedence graph which will be executed infinitely unless the manager specifies a certain number of iterations; Kang et al. [18] develop an approach for constraint-based allocation to optimize human resource allocation scheduling with accelerated simulated annealing, but becomes difficult to be implemented because of the increase of constraints.

In addition, the proposed researches are not always clear in real-world environment without consideration of some key factors which have impact on assignment applicability. In real cases, for example, more than one expert with some skills is demanded for a specific task when composing a team with the consideration of not only skill requirement, but also the negative propagation effects, which are ignored in most of the researches of team formation, to the efficiency of next tasks in a project.

B. COMMUNICATION EFFICIENCY

Communication is an essential tool in the field of project management, and the success of a project largely depends on the efficiency of its communication network, it is gaining importance every day and is the center of all management processes soon [49]. The project communication efficiency is influenced by such as project structure, communication media, communication frequency, circumstance, and relationship between project stakeholders [55], and directly influencing the cost and schedule in the project life cycle, which is illustrated as Figure 1 [49]. The processes of project communication are explained to include to identify stakeholders, to plan communications, to distribute information, to manage stakeholders' expectations, and to report performance in PMBOK, which is widely approved and accepted in many countries [44], and was also found to be characterized by how well information circulated among the project managers, between the coordinator and the stakeholders, as well as among the members of the project team [4]. There were a wide spectrum of researches that define and improve communication efficiency, for example, but not limited to the effective project communicator definition [43], and the enhancement of the project communication efficiency [15]. Due to the constraints in the real-life situations, such as project duration and human resources and cost, the impacts on communication efficiency of individual member with different skills will be considered to be the variables for the estimation of the project performance in this research instead.
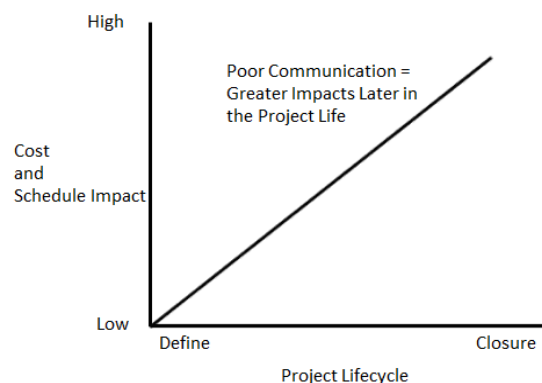

FIGURE 1. Price of poor communication [49].

From the literature reviewed, the methodology for human resource allocation and team formation is proposed with cost and time constraints basically. In order to be made closer to the real cases, negative efficiency and communication efficiency are extensively involved in this paper. Comparison on constraints and considerations between this paper and related researchers which have same objectives is summarized in Table 1.

TABLE 1
RELATIONSHIP BETWEEN THIS PAPER AND RELATED RESEARCHERS

Objectives	Research Attempt	Budget Constraints	Consideration of Communication Efficiency	Consideration of Negative Efficiency	Method	Data
Maximize Efficiency	Ge [57]	No	No	No	Evolutionary Algorithms	Simulated
	Our research	Yes	Yes	Yes	Integer programming	Real-world
Minimize Cost	Chen and Zhang [54]	No	No	No	Swarm Intelligence	Simulated
Maximize Efficiency and Minimize Cost	Liang and Chuang [56]	No	No	No	Evolutionary Algorithms	Simulated
Minimize Cost	Barreto et al. [3]	No	No	No	Constraint Satisfaction	Simulated

III. METHODOLOGY

This section proposes a model that assists to allocate human resource in a software development project based on integer programming, furthermore takes consideration of both cost and efficiency of human resource allocation for team formation in the software development project management based in a real case to maximize the performance to verge on customers' expectation that assists company to make decisions of whether the estimation of the tender is feasible based on existing resources, and in assignment in fixed project duration with labor skill and budget constraint.

Suppose a software company has m staff members and develops single project which is to be exercised during the time span $[0, T]$ and needs n skills to accomplish the project. Let $M = \{1, 2, …, m\}$ be a set of staff members and $S = \{1, 2, …, n\}$ be a skill set containing n skills. For skill $s \in S$, define $I(s) = \{I_1(s), I_2(s), …, I_{\lambda_s}(s)\}$ as the set of disjoint intervals in which skill s is required, where λ_s is the number of intervals in which skill s is demanded. Define $f(s, \lambda)$, $\lambda = 1, 2, …, \lambda_s$, as the number of staff members with skill s as demanded in interval $I_j(s)$ from start time $a(I_j(s))$ to finish time $b(I_j(s))$. More than one staff member could hold any kind of skills and a staff member could be associated with several skills with heterogeneous skill efficiencies. In the same interval, each staff member could be assigned to at most one skill. We denote by S_k the set of skills of staff member k, $k \in M$. Let e_{ks} denote the efficiency value of skill s of staff member k, and e_k^c the communication efficiency of staff member k which is related to the overall project efficiency. The labor cost is the major cost incurred in the management of a software development project that is strictly regulated by contracts. It is composed of (1) c_k^h, the hiring cost, which directly indicates the salary of

each staff member, k, and (2) c_{ks}^t, transferring cost, which occurs when a staff member's skill focus is assigned from an original skill to another one.

Assume that project effectiveness is calculated by summarizing the efficiency of all skills s over all staff members with the aim of maximizing the total value, and the consecutive skill efficiency would be disturbed when staff member who does not have maximizing efficiency of skill s is located in the previous skill assignment. In addition, the communication efficiency that could fill some vacancies left by the inadequate skill efficiency of individual staff members and the negative efficiency that occur in the next phase when an inappropriate staff member is assigned are considered. The notations that are used throughout the paper are listed in the following.

n: the number of skills.
m: the number of staff members.
B: the procurement budget of the project.
H: the planning span $[0, T]$ of the project.
$S = \{1, 2, …, n\}$: the set of n skills.
s: skill index, $s \in S$.
$M = \{1, 2, …, m\}$: the set of staff members.
k: index of staff members, $k \in M$.
$S_k \subseteq S$: the set of skills of staff member k, $k \in M$
$I = \{I_1, I_2, …, I_\lambda\}$: the set of λ disjoint intervals.
$I(s) = \{I_1(s), I_2(s), …, I_{\lambda_s}(s)\}$: the set of λ_s disjoint intervals in which skill s is required, $s \in S$
$a(I_j(s))$: the start time of interval $I_j(s)$.
$b(I_j(s))$: the finish time of interval $I_j(s)$.
$f(s, \lambda)$: the demand for number of staff members with skill s in interval I_λ.
e_{ks}: the efficiency value of skill s of staff member k, for $1 \le k \le m$, $1 \le s \le n$.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI
10.1109/ACCESS.2020.2975829, IEEE Access

IEEE *Access*

Hui Yi Chiang: Preparation of Papers for IEEE Access (January 2020)

e_{ks}^-: the negative propagation effects of staff member k with regards to skill s for $1\leq k\leq m$, $1\leq s\leq n$.

e_k^c: the communication efficiency value of staff member k, for $1\leq k\leq m$.

c_k^h: the monthly hiring cost of staff member k, for $1\leq k\leq m$.

c_{ks}^t: the transfer cost of staff member k to skill s from some other skill, for $1\leq k\leq m$, $1\leq s\leq n$.

p_λ^t: the tolerance value of efficiency of interval I_λ, for $1\leq\lambda\leq\lambda_s$.

Following the problem statements, we describe the problem in a mixed integer programming model. Suppose $x_{k\lambda} = 1$ is the value when staff member k is assigned to interval I_λ, otherwise $x_{k\lambda} = 0$, for $1\leq k\leq m$, $1\leq\lambda\leq l$; $y_{ks\lambda} = 1$ is the value when staff member k is assigned with skill s in interval I_λ, otherwise $y_{ks\lambda} = 0$, for $1\leq k\leq m$, $1\leq s\leq n$, $1\leq\lambda\leq\lambda_s$; $z_{ks\lambda} = 1$ is the value when staff member k is assigned with skill s in interval $I_{\lambda-1}$ and assigned in interval I_λ with different skills s^-, otherwise, $z_{ks\lambda} = 0$ for $1\leq k\leq m$, $1\leq s\leq n$, $2\leq\lambda\leq\lambda_s$.

Maximize

$$\sum_{k=1}^m e_k^c \left(\sum_{\lambda=1}^l x_{k\lambda} \right) + \sum_{k=1}^m \sum_{s=1}^n (e_{ks} + e_{ks}^-) \sum_{\lambda=1}^{\lambda_s} y_{ks\lambda} \quad (1)$$

subject to

$$\sum_{k=1}^m \left(e_k^c y_{ks\lambda} + \sum_{s=1}^n (e_{ks} + e_{ks}^-)y_{ks\lambda} \right) \geq \sum_{s=1}^n p_{s\lambda}^t f(s,\lambda) \quad (2)$$

$$\sum_{k=1}^m c_k^h \left(\sum_{\lambda=1}^l y_{ks\lambda} \left| b(I_\lambda(s)) - a(I_\lambda(s)) \right| \right)$$
$$+ \sum_{k=1}^m \sum_{s=1}^n c_{ks}^t \sum_{\lambda=2}^{\lambda_s} z_{ks\lambda} \leq B \quad (3)$$

Constraints (1) define the objective function to maximize project efficiency, which is summarized with the communication efficiency, skill efficiency, and negative efficiency of individual staff when assigned to different durations. To ensure the efficiency of the project, the tolerance efficiency is given as in constraints (2). In constraints (3), the cost that includes the salary of staff members and the additional cost incurred due to skills (roles) transfer within the project duration is upper bounded by the limited budget.

IV. COMPUTATIONAL EXPERIMENTS

To realize the proposed model, we conduct a case study at Company C, which was founded in 1996 with capital over seven hundred billion New Taiwan Dollars (US$ twenty-two billion dollars). Company C, which is listed on Taiwan's stock exchange and on the over-the-counter market, is the most representative company in terms of information and communication technology in Taiwan. For enterprise expansion and business transformation, software projects

implement related to information and communication technology is one of business strategies.

A bid of government project of information systems development from 2014 September 1st, 2014 to November 30th, 2015 had been won, and the cost of development is TWD 6,000,000 (US$ One hundred ninety thousand dollars) after deduction. The major deliverables and time phases of individual duration are summarized as Table 2, and the requirements of skills, staff numbers defined in the contract, and the tolerance efficiency calculated with internal estimation are listed in Table 3.

TABLE 2
PROJECT DATA OF THE INFORMATION SYSTEMS DEVELOPMENT

Project Duration	Item	Deliverables	Due Date
1	Project Kick Off	Project Management Plan	Within 10 days after the date of awarding the contract
2	Schedule Report	Project Status Report	On 10th every month after the date of awarding the contract
3	System Analysis	Requirement Interview Specifications System Analyst Specifications	2014/09/01 ~ 2014/10/31
4	System Design	System Design Specifications	2014/11/01 ~ 2015/01/31
5	System Development	System Development Specifications Unit Testing Plan Integration Testing Plan Code	2015/02/01 ~ 2015/08/31
6	Test and Verification	Function Testing Report Integration Testing Report	2015/09/01 ~ 2015/10/31
7	On Production Preparation	System Operation Manual System User Manual	2015/11/01 ~ 2015/12/15

According to the hiring salary data published on the website of government and recruitment orientation of Company C, hiring cost is listed. The value of transferring cost (TC), skill efficiency (SE), communication efficiency (CE), and negative value of efficiency (NE) are assumed based on the average grades calculated with weighting function of performance evaluation and indicated as Table 4 and Table 5. The transferring cost and negative efficiency are calculated with weights of salary, days of delay, and additional human resources of the next interval from the performance management model in Company C.

Because the model is constructed according to a real case in Company C, four variants are formulated to demonstrate the applicability of the proposed framework. In the simulation implemented with Gurobi, first, the cost constraints are taken off and staff is allocated with maximum efficiency, and second, the model proposed in this paper is formulated. To verify the influences from communication and negative efficiency, the third variant is formulated without cost

constraints or consideration of communication and negative efficiency. The model for minimizing cost is implemented in the fourth variant.

After the simulation models are implemented, the results of the bid of government project of information systems development are illustrated and discussed in Section V.

TABLE 3
REQUIREMENTS OF SKILLS, STAFF NUMBERS, AND THE TOLERANCE EFFICIENCY OF INDIVIDUAL DURATION

Project Duration	Required Skill and Staff Numbers					Tolerance Efficiency
	PM	SA	SD	PG	QA	
1	1					70
2	1					50
3		4				300
4		2	2			310
5		4	2	4		760
6		2			4	460
7	1	4				350

TABLE 4
SKILL EFFICIENCY (SE), TRANSFERRING COST (TC), AND NEGATIVE EFFICIENCY (NE)

Staff Member	Skill Item														
	PM			SA			SD			PG			QA		
	SE	TC	NE	SE	TC	NE	SE	TC	NE	SE	TC	NE	SE	TC	NE
A	80	0	-0	90	18	-0.5	70	41	-1	20	37	-4	60	41	-2.5
B	75	15	-4	90	15	-1	80	53	-2.5	70	72	-7	80	24	-2.5
C	60	30	-6	100	0	-0	80	20	-1	20	62	-5	50	20	-0.5
D	30	35	-5	60	27	-6	90	40	-1.5	80	27	-0.5	45	35	-4
E	60	31	-5.5	70	32	-5	75	15	-3	90	38	-1	50	24	-2
F	20	69	-7	40	66	-4.5	90	24	-1	100	15	-0	65	31	-3
G	10	76	-6.5	60	58	-4	20	20	-7	50	21	-5.5	75	22	-2
H	10	84	-6	20	60	-7	20	20	-7.5	40	22	-7.5	85	40	-0
I	70	33	-3.5	25	73	-6.5	10	47	-8	15	15	-5.5	100	0	-0
J	70	14	-0	80	13	-3	80	50	-6	30	88	-8	90	0	-0
K	50	27	-8	30	42	-6.5	50	10	-3.5	95	0	-0	70	0	-0
L	65	42	-4.5	55	34	-2.5	45	32	-4	75	16	-2.5	65	13	-3

TABLE 5
HIRING COST AND COMMUNICATION EFFICIENCY

Staff Member	Hiring Cost (TWD)	Communication Efficiency (CE)
A	70,000	25
B	64,000	20
C	65,000	30
D	49,000	10
E	55,000	5
F	67,000	25
G	42,000	15
H	45,000	50
I	51,000	20
J	63,000	30
K	56,000	10
L	60,000	5

V. RESULTS ANALYSIS AND DISCUSSION

To realize the feasibility and applicability of the proposed framework, we calculate the efficiency value and cost of our approach and those that only consider skill efficiency and hiring cost into four experiment results for illustrations and discussion as in the following:

A. EXPERIMENT 1: MAXIMIZE EFFICIENCY WITHOUT BUDGET CONSTRAINT

1) Budget constraint is not considered.
2) Each staff member with maximum efficiency including skill, communication, and negative efficiency on skill s has first priority in allocation.

Table 6 summarizes the results of efficiency-oriented allocation, without considering cost constraints. The efficiency value is 3430.5, and the cost is 6,594,063 (TWD), which is over project budget.

TABLE 6
RESULTS OF EFFICIENCY MAXIMIZATION WITHOUT COST CONSTRAINTS

Project Duration	Required Skills and Staff Members (efficiency value: 3430.5 / cost: 6,594,063)				
	PM	SA	SD	PG	QA
1	A				
2	A				
3		A B C J			
4		A C	F J		
5		A B C G	D J	E F H K	
6		A C			B H I J
7	I	A B C J			

B. EXPERIMENT 2: MAXIMIZE EFFICIENCY WITH BUDGET CONSTRAINT

1) Budget constraint is considered.

2) Efficiency including skill, communication and negative efficiency of each staff member is considered.

Table 7 illustrates the result of allocation based on proposed model of this paper. We make decisions with efficiency-oriented, cost constraint. The efficiency value is 3013.5, and the cost is 599,8335 (TWD), which is under project budget.

TABLE 7
ALLOCATION RESULTS OF EFFICIENCY MAXIMIZATION WITH COST CONSTRAINTS

Project Duration	Required Skills and Staff Members (efficiency value: 3013.5 / cost: 5,998,335)				
	PM	SA	SD	PG	QA
1	A				
2	A				
3		C G H J			
4		C G	D H		
5		B C G I	D J	E H K L	
6		B C			G H I J
7	I	A B G J			

C. EXPERIMENT 3: MAXIMIZE EFFICIENCY WITHOUT BUDGET CONSTRAINT

1) Budget constraint is not considered.

2) Each staff member with maximum skill efficiency skill s has first priority in allocation.

3) Communication and negative efficiency is not considered.

Table 8 illustrates the result of allocation of efficiency-oriented allocation, but the communication and negative efficiency, influential in real cases when implements software development projects, is not considered. The efficiency value is calculated as 2735, and the cost is 6656943 (TWD), which is over project budget.

TABLE 8
ALLOCATION RESULTS OF EFFICIENCY MAXIMIZATION WITHOUT COST CONSTRAINTS AND CONSIDERATION OF COMMUNICATION AND NEGATIVE EFFICIENCY

Project Duration	Required Skills and Staff Members (efficiency value: 2735 / cost: 6,656,943)				
	PM	SA	SD	PG	QA
1	A				
2	A				
3		A B C J			
4		A C	D F		
5		A B C G	D J	E F K L	
6		A C			B H I J
7	I	A B C J			

D. EXPERIMENT 4: MINIMIZE COST

1) Budget constraint is not considered.

2) Each staff member with minimum cost has first priority in allocation.

From another perspective, we get the allocation base on proposed subjection in this paper but minimization cost oriented instead. 5,843,165 (TWD) is under the budget constraints, but has the lowest efficiency value with 2500. The result of allocation is illustrated in Table 9.

TABLE 9
ALLOCATION RESULTS OF COST MINIMIZATION

Project Duration	Required Skills and Staff Members (efficiency value: 2500 / cost: 5,843,165)				
	PM	SA	SD	PG	QA
1	I				
2	H				
3		D G H J			
4		G J	D H		
5		D G I J	B E	C H K L	
6		D K			E G H I
7	I	D E G H			

According to the computational experiments, the results of the four variants are described in Table 10 and provided to Company C to make decisions on human resource allocation in a software development project from different perspectives. For maximum efficiency without budget constraints in Experiments 1 and 3, staff members with maximum skill efficiency have first priority, ; however, the quality of a project is very crucial to the goodwill of a company. Therefore, Experiment 2, which was calculated on the basis of the model proposed in this paper, might be more applicable in the case of Company C.

TABLE 10
ALLOCATION RESULTS OF FOUR VARIANTS

Exp. No	Cost	Efficiency	CE	NE	Budget Constraints
1	2nd Highest	1st Highest	√	√	
2	3rd Highest	2nd Highest	√	√	√
3	1st Highest	3rd Highest			
4	4th Highest	4th Highest	√	√	√

VI. CONCLUSIONS

Generally, human resource allocation in software development project is difficult to describe. The communication efficiency, transfer cost, and negative efficiency which impact the estimation and quality of software development projects are not addressed in most of the researches of human resource allocation and team formation. In this paper, more perspectives are considered for assisting company to make decisions on human resource allocation and project evaluation with cost, project duration, and efficiency constraints. This paper is based on a real case concept, including not only the basic consideration of staff numbers and salary but also adding more key factors. The results demonstrate that these factors could bring out different sources to help companies in making further evaluations for allocating staff in a software development project. To demonstrate the applicability of the proposed framework, four variants were discussed. Developing a project with cost constraints is the basic principle in the evaluation of a company. The key factors including communication and negative efficiency are relevant to maximizing project efficiency, which is related to project success and quality. Among the various issues for further research, it may be interesting to determine whether there are other decisions, objectives, or constraints that are worth considering for human resource allocation, team formation, or human resource training in software development projects. Also, staff type, regular assignment of employees, overtime work hours, maintenance after project settlement, and multi-project scenarios are additional topics for consideration.

REFERENCES

[1] A. Anagnostopoulos, L. Becchetti, C. Castillo, A. Gionis, and S. Leonardi, "Power in unity: forming teams in large-scale community systems," in *Proc. ACM Int. Conf. Inf. and Knowl. Manag.*, vol.10, pp.599–608, 2010.

[2] A. Anagnostopoulos, L. Becchetti, C. Castillo, A. Gionis, and S. Leonardi, "Online team formation in social networks," in *Proc. ACM Int. Conf. World Wide Web*, vol.12, pp.839–848, 2012.

[3] A. Barreto, M.D.O. Barros, and C.M.L. Werner, "Staffing a software project: a constraint satisfaction and optimization-based approach," *Comput Oper Res*, vol. 25, pp.3073–3089, 2008.

[4] A. Diallo and D. Thuillier, "The success of international development projects, trust and communication: an African perspective," *Int J Proj Manag*, vol.23, no.3, pp.237–252, 2005.

[5] A. Drexl, "Scheduling of project networks by job assignment," *Manag. Sci*, vol.37, pp.1590-1602, 1991.

[6] A. Ernst, H. Jiang, M. Krishnamoorthy, and D. Sier, "Staff scheduling and rostering: A review of applications, methods and models," *Eur. J. Oper. Res.*, vol.153, pp.3–27, 2004.

[7] A. Majumder, S. Datta, and K.V.M. Naidu, "Capacitated team formation problem on social networks", in *Proc. ACM SIGKDD Int. Conf. Knowl. Discovery and Data Mining*, vol.12, pp.1005–1013, 2012.

[8] B. Maenhout and M, Vanhoucke, "An exact algorithm for an integrated project staffing problem with a homogeneous workforce," *J. Scheduling*, vol. 19, no.2, pp.107-133, Apr. 2016.

[9] C. Heimerl and R. Kolisch, "Scheduling and staffing multiple projects with a multi-skilled workforce", *OR Spectrum*, vol.32, pp.343-368, 2010.

[10] C. K. Chang, C. Chao, M.J. Christensen, and T.T. Nguyen, "Software project management net: a new methodology on software management," *P Int Comp Softw App*, 1998.

[11] C. K. Chang, H. Jiang, D. Zhu, Y. Di, and Y. Ge., "Time-line based model for software project scheduling with genetic algorithms," *Inf. Softw. Technol.*, vol. 50, pp.1142–1154, 2008.

[12] C. Stylianou, A. Andreou, G. Ruhe, and C. Wohlin, "Human resource allocation and scheduling for software project management" *Software Project Management in a Changing World*, Berlin, Germany: Springer, pp.73-106, 2014.

[13] C. T. Li, M.-K. Shan, and S.-D. Lin, "On team formation with expertise query in collaborative social networks," *Knowl Inf Syst*, vol.42, no.2, pp.441–463, 2015.

[14] D. Catrysse and L.N. Van Wassenhove, "A survey of algorithms for the generalized assignment problem," *Eur J Oper Res*. vol.60, pp.260–272, 1992.

[15] D. Cooke, "The real success factors on projects," *Int. J. Proj. Manag.*, vol.20, pp.85–190, 2002.

[16] Denis C. Pinha, Rashpal S. Ahluwalia, and Pedro Senna, "The combinational multi-mode resource constrained multi-project scheduling problem," *Int. J. Supply and Oper Manag,* vol.3, no.3, pp.1391-1412, 2016.

[17] D. Haughey, "Understanding the project management triple constraint," *Project Smart*, 12-Dec-2011. [Online]. Available: https://www.projectsmart.co.uk/understanding-the-project-management-triple-constraint.php.

[18] D. Kang, J. Jung, and D.H. Bae, "Constraint-based Human Resource Allocation in Software Projects," *Software Practice Experience*, vol. 41, pp.551–577, 2011.

[19] E. Demeulemeester, "Minimizing resource availability costs in time-limited project networks," *Manag. Sci*, vol.41, pp.1590-1598, 1995.

[20] F. Ghasemian, K. Zamanifar, N. Ghasem-Aqaee, and N. Contractor, "Toward a better scientific collaboration success prediction model through the feature space expansion," *Scientometrics*, vol.108, no.2, pp.777–801, 2016.

[21] F. Liang, S. Lawrence, "A goal programming approach to the team formation problem," Leeds School of Business, University of Colorado, 2007.

[22] G. Jin, "Management of the design process: human resource allocation in factory of the future," Université de Bordeaux, 2019.

[23] Günther Ruhe and Claes Wohlin, *Software Project Management in a Changing World*, 2014.

[24] G. Vairaktarakis, "The value of resource flexibility in the resource-constrained job assignment problem," *Manag. Sci.*, vol.49, pp.718–732, 2003.

[25] H. Alfares and J. Bailey, "Integrated project task and manpower scheduling," *IIE Trans*, vol.29, pp.711–717, 1997.

[26] H. Wi, S. Oh, J. Mun, and M. Jung, "A team formation model based on knowledge and collaboration," *Expert Syst Appl*, vol.36, no.5, pp.9121–9134, 2009.

[27] J. Bailey, H. Alfares, and W. Lin, "Optimization and heuristic models to integrate project task and manpower scheduling," *Comput Ind Eng*, vol.29, pp.473–476, 1995.

[28] Jorge E. Gomar, Carl T. Haas, and David P. Morton, "Assignment and allocation optimization of partially multiskilled workforce," *J Constr Eng M ASCE*, vol.128, no.2, pp.103–109, 2002.

[29] J. R. Turner, "The management of project-based organization: A personal reflection," *Int. J. Proj. Manag.*, vol.36, pp.231–240, 2018.

[30] L. C. Silva and A. P. C. S. Costa, "Decision model for allocating human resources in information system projects," *Int. J. Proj. Manag.*, vol. 31, no.1, pp.100-108, 2013.

[31] L. Ozdamar and G. Ulusoy, "A survey on the resource-constrained project scheduling problem," *IIE Trans*, vol.27, pp.574–586, 1995.

[32] M. Bassett, "Assigning project to optimize the utilization of employees' time and expertise," *Comput Chem Eng.*, vol.24, pp.1013–1021, 2000.

[33] M. Cross, "Multi-skilling brings cost and productivity benefits. Proc.," *Training Plan Management: 11th National Maintenance Engineering Conference*, U.K, 1996.

[34] Michael Gentile, Ronald D. Collette and Thomas D., *The CISO Handbook*, Aug. 2005, p.172.

[35] M. Kargar and A. An, "Discovering top-k teams of experts with/without a leader in social networks," in *Proc. ACM Int. Conf. Inf. and Knowl. Manag.*, vol.11, pp.985–994, 2011.

[36] M. Kargar, A. An, and M. Zihayat, "Efficient bi-objective team formation in social networks," *Lect Notes Artif Int*, vol.7524, pp.483–498, 2012.

[37] Michael W. Newell and Marina N. Grashina, *The Project Management Question and Answer Book*, 2004, p.8.

[38] M. Sorkhi, S. Hashemi, and A. Hamzeh, "An effective expert team formation in social networks based on skill grading," in *Proc. of IEEE Int. Conf. Data Mining Workshops*, vol.11, pp.366–372, 2011.

[39] N. Beaumont, "Using mixed integer programming to design employee rosters," *J. Oper. Res. Soc.*, vol.48, pp.585–590, 1997.

[40] N. Thorne, "Project Management Triangle," *Nick's Digital Solutions*, 18-Apr-2016. [Online]. Available: http://www.nicksdigitalsolutions.com/project-management-triangle/.

[41] O. Icmeli, S. Erenguc, and C. Zappe, "Project scheduling problems: A survey," *Int. J. Oper. Prod. Manag*, vol.13, pp.80–91, 1993.

[42] Pamela McGhee and Peter McAliney, *Painless Project Management*, 2007, p.74.

[43] P. Hersey, K. Blanchard, and D. Johnson, "Management of Organizational Behavior: Leading Human Resources," NJ: Prentice Hall, 2001.

[44] Project Management Institute, *A guide to the Project Management Body of Knowledge (PMBOK guide)*, 2017.

[45] R. C. Burleson, C. T. Hans, R. L. Tucker, and A. Stanley, "Multiskilled labor utilization strategies in construction," *J. Constr Eng M.*, vol.124, no.6, pp.480–489, 1998.

[46] R. M. Willamson, "Optimum performance through multi-skill maintenance," *AIPE Facilities*, Apr, 1992.

[47] R. Mohring, "Minimizing costs of resource requirements in project networks subject to a fixed completion time," *Oper. Res.*, vol.32, pp.89–120, 1984.

[48] R. Reagans, E. Miron-Spektor, and L. Argote, "Knowledge utilization, coordination, and team performance," *Organ. Sci.*, vol.27, no.5, pp.1108-1124, 2016.

[49] S. Rajkumar, "Art of communication in project management," *PMI® Research Conference: Defining the Future of Project Management*, Washington, DC. Newtown Square, PA: Project Management Institute, 2010.

[50] T. Guldemond, J. Hurink, J. Paulus, and J. Schutten, "Time-constrained project scheduling," *J. Scheduling*, vol.11, pp.137–148, 2008.

[51] T. G. Shree Raja Gopal and K. Murali, "Analysis of factors affecting labour productivity in construction," *Int. J. Recent Sci. Res.*, vol.7, no.6, pp.11744–11747, 2016.

[52] T. Lappas, K. Liu, and E. Terzi, "Finding a team of experts in social networks," in *Proc. ACM SIGKDD Int. Conf. Knowl. Discovery and Data Mining*, vol.09, pp.467–475, 2009.

[53] V. Balachandran, "An integer generalized transportation model for optimal job assignment in computer networks," *Oper Res*, vol. 24, no.4, pp.742–749, 1976.

[54] W. Chen and J. Zhang "Ant colony optimization for software project scheduling and staffing with an event-based scheduler," *IEEE T Software Eng*, vol. 39, no.1, 2013.

[55] X. L. Cao, L. W. Chen, and Y. Li, "An evaluation model of project communication efficiency based on entropy method and CGC theory," *Int C Manage Sci Eng (20th) (ICMSE)*, 2013.

[56] Y. C. Liang, and C. Y. Chuang, "Variable neighborhood search for multi-objective resource allocation problems," *Robotics and Computer-Integrated Manufacturing*, vol.29, pp.73-78, 2013.

[57] Yujia Ge, "Software project rescheduling with genetic algorithms," *Int. Conf. on Artif. Intelligence and Computational Intelligence*, Shanghai, China, pp.7–8, 2009.