A preliminary approach for modelling and planning the composition of engineering project teams

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Abstract: Managing engineering projects is a complex activity involving multiskilled engineers, who have varying levels of capability in these skills. This paper outlines a preliminary approach to modelling and planning the composition of engineering project teams, taking into consideration the skills and capabilities of engineers and the nature of the project work to be undertaken. The approach includes a simple means of identifying engineers' skills and then quantifying their level of capability in these skills. Subsequently, the approach uses a genetic algorithm along with a task-to-engineer allocation strategy to establish how best to utilize the mix of skills and capabilities of the team of engineers assigned to the project under consideration. The approach also provides a means of identifying imbalances or shortfalls in skill and capability within a team, and the formulation of an appropriate development strategy to redress/overcome them. An application of the approach to an industrial case study is presented, which led to significant potential reductions in expected project duration and labour cost. These potential reductions could be achieved by appropriately modelling engineers' skills and capabilities, and redressing the imbalance within the team through proposed changes to its composition.

Keywords: project management, engineering teams, engineer skills and capabilities

1 INTRODUCTION

Large engineering projects are becoming increasingly more challenging to manage as they involve numerous interdependent tasks of varying complexity, and many engineers with a range of skills and level of capability in these skills. Engineering projects on such a scale require sufficient expertise in a broad set of skills to avoid extended durations and increased costs. Pemberton-Billing *et al.* [1] note that in many industries, due to the size of projects and the range of skills required, the engineering team is an essential component of most successful projects; i.e. bringing together individuals with the correct balance of skills is viewed as being fundamental to successfully completing the complex range of tasks involved in projects. Indeed, a statistical analysis performed by

Odusami *et al.* [2] showed that a significant relationship exists between project team composition and overall project performance. Similarly, Farr-Wharton [3] conducted a study highlighting the contribution individuals make, and their assembly into talented and balanced teams, as important factors to the successful completion of projects.

In the current knowledge-based economy, employee skills and abilities, also referred to as human capital, are fast becoming an organization's most valuable asset [4, 5], a key driving force in economic development [6–8], and a source of competitive advantage [9–11]. Elias and Scarbrough [12] state that 'in particular, emphasis has been placed on the importance of a company's human capital – the value-creating skills, competencies, talents, and abilities of its workforce – as an essential component of gaining competitive advantage'. Indeed, human capital is high on the policy agenda of national governments and international organizations [6]. The United Kingdom's government has been widely

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reported as recognizing the growing importance of intangible assets, which include skills or human capital [7, 8, 10]. Butler *et al.* [10] indicate that British businesses must compete by exploiting capabilities, such as skills and knowledge, which its competitors cannot easily match or imitate. Further, it is stated 'the United Kingdom's government would like to see better guidance for companies of all sizes on assessing the strengths and weaknesses of their intangible assets, including the skills of their people'. Similarly, Allen and van der Velden [6] recognize that there is now a greater need to monitor and assess the stock of human capital. In addition, Elias and Scarbrough [12] report wide recognition that companies need to develop mechanisms to determine the value of their employee base.

Traditionally within engineering companies, decisions regarding the composition of a project team involve managers using their judgement and experience to select the most appropriate engineers given the nature of the tasks to be undertaken. The complexity of this decision making is compounded since engineers can be multiskilled with varying levels of capability in these skills, and different tasks require specific skills. Therefore, difficulties lie in knowing what specific skills and level of capability in these skills engineers possess, and which engineers should be included in the project team. Higgs *et al.* [13] indicate that experience, talent, and education can form the basis for the selection of people for roles within teams. However, it is noted that an individual's success in meeting a team role depends on how well his or her skills, characteristics, and experiences match the team role requirement. Tseng *et al.* [14] assert that the formation of multifunctional teams is becoming a key issue in project management. However, the right combination of members to be included within a team is very difficult to specify, and therefore a significant challenge exists in forming a good project team. Failure to select the right team members can result in extra budget being consumed, missed deadlines, and accompanying compensation payments to clients. On this theme, Castka *et al.* [15] indicate that incorrect team composition will produce critical skill gaps, which will inevitably lead to a decrease in overall team performance. In spite of the widely acknowledged importance of teams in organizations, it is reported that limited research has been conducted on providing analytical solutions for team formation [14, 16].

Based on the difficulties highlighted, there is a need to assist project managers in modelling and planning the composition of their engineering teams so that projects can be performed efficiently. In pursuit of this need, this paper presents a preliminary approach, which includes a simple means of how to identify the skills and quantify the capabilities of engineers such that the composition of an engineering team can be tailored with regard to the project tasks to be undertaken. Further, if the engineers in a company do not have the required expertise to efficiently undertake certain tasks, project managers require a means of identifying development needs in terms of skills and capabilities. Therefore, the approach also offers a means of identifying any imbalance or shortfall in skill and capability within an engineering project team, and formulating a development strategy, which if implemented would redress the imbalance and overcome the shortfall, and better position the company to face the challenges posed by future projects.

The remainder of this paper is organized as follows. Section 2 builds on the introduction by presenting a synopsis of related work. Section 3 provides an overview of the preliminary approach. In section 4, the approach is applied retrospectively to an industrial case study, which is then discussed in section 5. Finally, section 6 presents conclusions and the direction of future work.

2 RELATED WORK

It has been recognized by Andreasen *et al.* [17] that much time and effort is lost in engineering projects due to a lack of focus on managing work, which exposes considerable scope for improvements and efficiency gains to be made. Duffy *et al.* [18] highlight continuous improvements in existing approaches to managing engineering, and the introduction of new approaches will remain the focus of research until adequate solutions, which can be implemented in industry, can be found. Indeed, a well-thought-out process or system of management is acknowledged as being central to the efficient performance of an organization [19], which relies on the effective utilization of the available talents, skills, and resources [20].

Butler *et al.* [10] expect regular measuring of skills to become commonplace, which could contribute to improving organizational performance. Indeed, organization teams are viewed as important contributors in improving organizational performance [6, 7, 10, 21, 22]. Tether *et al.* [7] suggest that quantitative studies should be conducted in order to explore the relationship between skill compositions and performance at a company level. As a result of an exploratory research study, Mendibil and MacBryde [22] indicate that to enable a team to simultaneously, increase its contribution to the business and motivate and develop the team and its individuals, there is a requirement for a tool that facilitates the design of effective *team-based*

performance measurement systems (TPMSs). Further, it is suggested that a TPMS has the potential to be used as a team development tool. Beech and Crane [21] indicate that skills and team working have a major impact on corporate performance. Indeed, teamwork has been viewed as one of the most influential factors in successful companies in bringing about significant improvements in productivity [3, 15] and contributing to maximizing organizations' capability and responsiveness [23]. Higgs *et al.* [13] report that when reviewing the literature on team composition and relating it to team performance, it becomes apparent that, depending on the nature of the task, factors such as team cohesion are required for the successful completion of the task.

Academic interest is growing in the area of representing an organization's capability so that it can be viewed externally as offering a range of services rather than developing specific products [24]. Such views of an organization, referred to as *competence profiles or portfolios*, are reported as facilitating the creation of virtual enterprises, which involve several companies forming temporary alliances to address some need [24, 25]. Further research on the theme of competence has been conducted on analysing and managing organizational competence [26–28], which has been viewed as the collective skills, abilities, and expertise of individuals and groups within organizations [9]. Such research aims to define competence at a company level, which as alluded to earlier can be useful for purposes such as the strategic formation of virtual enterprises.

At an individual level within a company, a means of quantifying the degree of engineers' skills and capabilities is required to assist project managers in the decision-making process regarding the composition of a project team. In turn, this will facilitate the effective allocation and utilization of engineers with regard to the varying project tasks, given that each task requires particular expertise. It has been recognized by Homer [4] that by not effectively matching together employees' skill ability and work, productivity can be greatly reduced. Similarly, Matsumoto *et al.* [5] report that employees' competency in performing skills and a company's ability to deploy them is a significant factor in determining the company's success. Ra [29] notes that managers faced with staffing decisions would benefit from having a computerized tool, which allows a profile of the ideal person for a given position to be entered and then searches a database of the available talent within an organization returning a listing of qualified candidates most suitable for a position on the project team. Likewise, Homer [4] cites a competency management system as enabling a company to search the skill profiles of current staff, such that when a contract for work is won and profiles have been drawn up for the ideal people they need to staff their project team, a list is generated of all the people in their organization with those skills. Similarly, Rothwell and Lindholm [9] suggest that competency models are used to enable an organization to staff its positions with employees who possess the characteristics of *job exemplars*.

With regard to the skills of an individual, research literature differentiates between soft and hard skills [6, 7, 13, 21, 30–32]. Spinks *et al.* [31] view hard skills as those primarily related to a technical domain, which are underpinned by a strong theoretical base. Further, with a particular focus on engineers, hard skills are referred to as defining skills, which are said to be unique to the engineer and encompass a sound knowledge of the engineering fundamentals within their discipline. On the other hand, soft skills are seen as social and interpersonal skills that enable effective performance in a commercial working environment. Collectively, soft skills have been defined as including communication skills, presentation skills, teamwork skills, collaborative problem-solving skills, conflict resolution skills, planning skills, and customer-handling skills [7, 12, 30, 31]. In the research reported, it has been widely recognized that companies desire individuals with both hard and soft skills.

Allen and van der Velden [6] report that most research and existing studies have focused on aspects of hard skills, i.e. highly specific skills pertaining to particular tasks, since these are relatively well-defined and accessible to measurement under controlled conditions. Interestingly, Delbridge *et al.* [8] point out that the UK's national skill stocks are mainly measured in the form of formal qualifications. In contrast, soft skills are conceptually more difficult to measure [6, 7, 12]. Also, it is reported that the breadth and variety of specific and generic skills presents a major potential stumbling block for researchers attempting to take stock of human capital [6]. Further, a variety of methods commonly used to assess skill levels are cited including: objective measures through assessment and testing, subjective measures through supervisor rating, and self-assessment.

Finding a way to quantify a person's skills and experience is recognized as a fundamental problem and a significant challenge [29, 33]. While not offering a means of eliciting measures of skills and experience, Ra [29] proposes a simple numerical scale ranking level of experience from 0 to 9, where 0 represents no experience and 9 represents expert/specialist. Similarly, Matsumoto *et al.* [5] suggest employees' skill performance scores being rated from 1 to 5, where 1 represents no ability and 5 represents an expert understanding. On the theme of scoring skills, although with regard to self-assessment, it is reported

that there is no natural scale on which to measure skills, which is seen as placing a burden on researchers to provide a scale that is uniformly understood by all respondents [6]. Also, Elias and Scarbrough [12] report that the research suggests there is no universal formula to score the value of employee skills and competencies. Whatever scale is used to represent an individual's skills, it has been recommended that it should be based on a combination of professional training, academic qualifications, and practical experience [5, 29]. While numerical scales have been used as an aid to team formation [5, 29], an alternative approach has been described in which the membership of a team is related to the engineering characteristics of the product being developed [16]; i.e. based on an overall goal, a set of customer requirements is developed, which are mapped to engineering characteristics that are then related to the possible team members.

Organizations need to maintain a strategic approach to their business, constantly assessing their strengths and weaknesses, if they are to remain competitive [34]. Beech and Crane [21] state 'it has long been argued that the adoption of Human Resource Management policies focusing on the development of people and their involvement in teams could and should enhance individual and organisational performance'. By identifying skill strengths and weaknesses at a team level, workload can be better matched with skill strengths, and training strategies can be developed to address skill weaknesses or skill gaps in its future business needs [5, 15]. Spinks *et al.* [31] indicate that companies adopt a number of strategies in response to perceived skill deficiencies including upskilling by increasing training, inskilling through intensified recruitment efforts, and outskilling through the use of third parties to undertake skilled work. Indeed, it is recognized that by not appropriately managing peoples' skills, an organization could be wasting money on ineffective training programmes and strategies [4]. Therefore, skills management is reported as growing in popularity in the human resource management community. The capability to assess competencies and determine skill gaps enables organizations to implement more cost-effective and meaningful training and development practices so that their specific business goals can be met.

3 OVERVIEW OF THE PRELIMINARY APPROACH

The preliminary approach is aimed at assisting project managers across a range of engineering industries by contributing towards efficient project performance. The approach provides a means of enabling project managers to identify engineers' skills and then quantify their capabilities, in relation to the tasks to be undertaken, such that the composition of project teams can be effectively planned, leading to the competitive completion of engineering projects in terms of timescale and cost. In addition, the approach enables the identification of any imbalance or shortfall in a team's expertise and, in response, the formulation of an appropriate development strategy to redress/overcome them. An overview of the preliminary approach is shown in Fig. 1.

Initially, through consultation with project managers, engineers' skills are identified and the level of capability in these skills is quantified. Project managers perform their subjective assessment based on the defined tasks in the project under consideration and historical information such as engineers' performance in corresponding or similar tasks undertaken in past projects. Numerical representation of an engineer's level of capability in skills is essential for a purposeful analysis to be performed. More specifically, the numerical representation is compatible in the subsequent production of a project schedule, in the next step of the approach, since the expected time taken to complete any given task by any given engineer can be determined using the task's datum duration and the engineer's level of capability in the associated skill.

Once engineers' skill capabilities have been quantified, the initial model of the engineering project team can be represented. In consideration of this model of the team and the defined project tasks, a genetic algorithm (GA) and a task-to-engineer allocation strategy, both of which were developed for the approach, are applied, leading to the generation of a proposed project schedule. Jointly, the GA and allocation strategy manage the complexities involved in distributing interdependent project tasks among engineers who have different levels of capability in various skills, while simultaneously minimizing the project's expected duration and labour cost.

An analysis is performed on the proposed project schedule generated facilitating the composition of the engineering project team to be planned, leading to the appropriate representation of engineers' skills and capabilities. In addition, an analysis of the proposed project schedule leads to the identification of any imbalance or shortfall in the skills and capabilities of engineers in the project team. To assess the magnitude of any imbalance or shortfall in expertise, task duration-to-capability ratios are determined. Awareness of any imbalance or shortfall in expertise defines the formulation of an appropriate development strategy, such as developing the skills and capabilities of existing engineers and/or recruiting engineers with skills and capabilities needed to fill the gaps within the team.
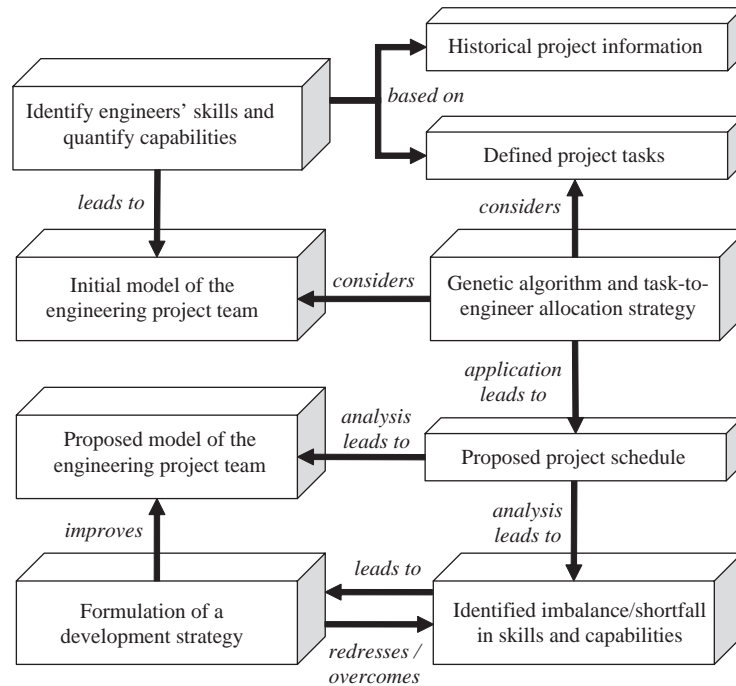
Fig. 1 Overview of the preliminary approach

4 INDUSTRIAL CASE STUDY

The case study was provided by domnick hunter Limited, which is an organization consisting of an international group of companies involved in the development and provision of filtration, purification, and separation products for various industries and applications. The case study relates to a project involving the design development of compressed air treatment equipment, which was undertaken by a team of nine multiskilled engineers from the Research and Development (R&D) department. The approach was applied retrospectively to the project, which the organization estimated to have a duration of 60 weeks.

To identify the skills of the engineers, first the project tasks associated with each skill needed to be specified. Table 1 summarizes the 15 skills associated with the 190 project tasks. Discussions with the R&D manager resulted in information being elicited regarding what skills each engineer possessed, and levels of capabilities in these skills. To identify the skills of an engineer, the R&D manager made use of historical project information. Specifically, if an engineer had previously worked on tasks, or similar tasks, associated with a skill needed for the project under consideration, then that individual was identified as having some capability in that skill. Subsequently, for each skill of each engineer, the R&D manager quantified the level of capability by using the most proficient individual in that skill as a benchmark.

Initially, this involved defining the datum duration of each task associated with each skill; i.e. the datum

Table 1 Skills and associated tasks related to the engineering project

Skill	Description	Number of tasks
S01	Costing analysis	9
S02	Drawings of castings	16
S03	Machining of castings	21
S04	Machining of other components	35
S05	Desiccant drum	5
S06	Air cooler	5
S07	Drum motor	5
S08	Other componentry	38
S09	Prototype build	2
S10	Review size build	4
S11	Amend drawings	10
S12	Technical analysis	23
S13	Revised build	2
S14	Generate BOMs/final modifications	3
S15	Testing	12

duration of a task with an associated skill, say task T_i and skill S_j, was defined as the time taken to complete the task, $t_{S_j}^{T_i}$, by the most proficient engineer able to undertake the task. Again, the R&D manager identified this engineer by consulting historical project information. Further, any engineer, say engineer E_k, was estimated to be able to complete task T_i associated with skill S_j in a given time, $t_{S_j,E_k}^{T_i}$. Consequently, the engineer's level of capability in the skill (SC) associated with the tasks was defined as

$$SC_{E_k,S_j} = \frac{\sum_{i=1}^{n} t_{S_j}^{T_i}}{\sum_{i=1}^{n} t_{S_j,E_k}^{T_i}} \qquad (1)$$

where n represents the number of tasks associated with the skill. Therefore, in the case of an engineer unable to undertake all of the tasks associated with a particular skill, in equation (1) the denominator is zero, and consequently the engineer's level of capability in this skill is defined as zero. Conversely, for an engineer viewed as being the most proficient in all tasks associated with a skill, in equation (1) the numerator and denominator are equal, leading to a level of capability in this skill of unity. In all other cases, the engineer's level of capability in a skill will lie between zero and unity.

As an example, let a skill, say skill S_1, associated with five tasks be defined as having datum durations 10, 15, 15, 10, and 20 units of time respectively. If an engineer, say engineer E_1, is estimated to be able to complete the tasks associated with this skill in 15, 20, 25, 15, and 25 units of time respectively, then the engineer's skill capability would be determined as

$$SC_{E01,S01} = \sum_{i=1}^{5} \frac{t_{S01}^{T_i}}{t_{S01,E01}^{T_i}} = \frac{10+15+15+10+20}{15+20+25+15+25} = 0.7 \quad (2)$$

This means of scoring and representing an engineer's level of skill capability is directly relevant to the preliminary approach since it is compatible with the production of a project schedule using the GA and tasks-to-engineer allocation strategy; i.e. with the objective of simultaneously minimizing the project's expected duration and labour cost, the GA and task-to-engineer allocation strategy are able to determine the expected time taken to complete any given task by any given engineer. Specifically, the expected time taken to complete any task is equal to its datum duration divided by the engineer's level of capability in the skill associated with the task. Although not indicated in Table 1, as explained each project task has a datum duration based on being undertaken by an engineer with a capability of unity in the associated skill. Table 2 shows the initial model of the engineering project team representing the engineers' skills and levels of capability in these skills.

In Table 2, each cell contains a numerical value on a scale of 0 to 1, which indicates an engineer's level of capability for each respective skill. A value of zero indicates that the engineer is unable to undertake tasks of the associated skill. Conversely, a non-zero value signifies that an engineer is capable of undertaking tasks of the associated skill. In addition to assigning levels of capability in terms of skills, each engineer was also allocated a labour cost per unit time, which is used in generating proposed project schedules.

Using the GA and the task-to-engineer allocation strategy, with the aim of minimizing the project's expected duration and labour cost, a datum proposed project schedule was generated. From this schedule, in which the 190 tasks were allocated among the nine engineers, the project's expected duration and labour cost were calculated to be 64 weeks and 223 554 units respectively. As stated earlier, the organization estimated the project duration to be 60 weeks. The discrepancy between the organization's expected project duration and that obtained from the schedule was deemed acceptable in terms of enabling subsequent comparisons to be made for proposed compositions of the engineering project team.

Importantly, in the datum proposed project schedule, tasks were allocated to all nine of the engineers. However, on inspection of the schedule, engineers' with lower levels of capability in a skill were predominantly not allocated tasks associated with that skill. Consequently, a decision was made to execute the GA and allocation strategy again, with engineers' lower-level capabilities excluded from consideration; i.e. engineers' lower levels of capability in a skill were set to zero, thus preventing them from being allocated tasks associated with that skill. Table 3 presents the five cases involving the exclusion of lower-level capabilities. For each case, the project's expected duration and labour cost are shown, which were obtained from the corresponding proposed project schedule produced using the GA and task-to-engineer allocation strategy.

Table 2 Initial model of the engineering project team

Engineer		Skills and capabilities														
Index	Cost per unit time	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14	S15
E01	12	0.3	0	0	0	0	0	0	0.2	0.4	0	0.1	0	0.5	0.1	0.6
E02	20	0.9	0.1	0.1	0.1	0.5	0.5	0.5	0.2	0.1	0	0	0.9	0	0.1	0.1
E03	20	0.7	0.1	0	0	0.8	0.5	0.5	0.2	0.7	0.8	0	0	0.7	0.1	0.7
E04	15	0.5	0.9	0.9	0.9	0.1	0.5	0.3	0.7	0.5	0.6	0.8	0	0.5	0.8	0.2
E05	17	0.7	1.0	0.9	0.9	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0	0.5	0.8	0.2
E06	0	0	0	0	0	0	0	0	0	0	0	0	1.0	0	0	0
E07	17	0.5	0.1	0	0	0	0.3	0.2	0.5	0.8	0.9	0	0	0.9	0.1	0.9
E08	12	0	0	0	0.3	0.3	0	0.2	0.3	0	0	0	0	0	0	0
E09	17	0.5	0.1	0	0	0	0	0.3	0	0	0	0	0	0	0	0

Table 3 Engineer skill–capability cases

Case	Description	Expected duration (weeks)	Labour costs (units)
1	Exclude capabilities of 0.1	39.2	134 762
2	Exclude capabilities of 0.1–0.2	36.0	124 106
3	Exclude capabilities of 0.1–0.3	38.1	118 258
4	Exclude capabilities of 0.1–0.4	37.8	117 174
5	Exclude capabilities of 0.1–0.5	45.5	109 443

Table 4 Task duration-to-capability ratios for Case 2

Skill	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14	S15
Ratio	7	39	21	43	10	16	18	122	16	5	39	162	5	48	89

Table 5 Engineer utilization – Case 2

Engineer	E01	E02	E03	E04	E05	E06	E07	E08	E09
Utilization (%)	0	88.3	67.2	97.2	83.3	88.9	91.1	83.9	1.1

From Table 3, it is observed that Case 2, in which engineers' capabilities of 0.2 or less are excluded, provides the lowest expected duration of the project. Specifically, the project was scheduled to be completed in 36 weeks as opposed to 64 weeks for the datum proposed project schedule. In addition to this 44 per cent reduction in the project's expected duration, a reduction of 44 per cent in labour cost is observed with respect to the datum proposed project schedule. As shown in Table 3, Case 5, involving engineers' capabilities of 0.1 to 0.5 being excluded, results in the greatest expected duration for the project. The reason for this increase is attributed to engineers with capabilities of 0.5 not being allocated tasks that they would be ordinarily. Thus, while it is useful to exclude engineers' lower levels of capability there is a threshold beyond which the expected duration of the project will increase.

For Case 2, an analysis was performed on the proposed project schedule to identify any imbalance in the project team with respect to the engineers allocated to undertake the tasks associated with each skill. The analysis entails identifying the engineer allocated to each task and then dividing the task's datum duration by the engineer's level of capability for the associated skill. For each skill, the expected task durations were then summed and divided by the cumulative capabilities of the engineers allocated to the associated tasks. Based on this analysis, task duration-to-capability ratios were calculated, as shown in Table 4.

In Table 4, the ratios for skills S08 and S12 are relatively greater than for other skills, signifying a noticeable imbalance in the project team. Attempts to redress this imbalance were proposed using two strategies: (a) recruiting an engineer to the project

Table 6 Engineer skill–capability cases

Case	Description
6	Recruit an engineer with a capability of 1.0 in skill S08
7	Recruit an engineer with a capability of 1.0 in skill S12
8	Recruit an engineer with a capability of 1.0 in skills S08 and S12
9	Develop engineers E01 and E09 to have a capability of 1.0 in skill S08
10	Develop engineers E01 and E09 to have a capability of 1.0 in skill S12
11	Develop engineers E01 and E09 to have capabilities of 1.0 in skills S08 and S12

team with the appropriate level of capability in the deficient skills and (b) developing existing engineers in the project team, leading to improvements in their level of capability in the deficient skills.

As shown earlier in Table 2, with regard to skill S12, only engineers E02 and E06 are able to complete associated tasks with capability levels of 0.9 and 1.0 respectively. Thus, scope to develop these engineers is negligible. On inspecting the proposed project schedule for Case 2, the utilization was seen to be insignificant for engineers E01 and E09, as shown in Table 5.

Given the lack of utilization of engineers E01 and E09, they were selected to be developed. The proposed changes to the project team are shown in Table 6, in which each case reflects changes in addition to excluding engineers' capabilities of 0.2 and less.

Figure 2 shows the project's labour cost versus expected duration associated with each proposed project schedule produced using the GA and task-to-engineer allocation strategy, for Cases 6 to 11 considered in Table 6 and Cases 1 to 5 considered in Table 3.

In Fig. 2, the lowest expected duration to complete the project corresponds with Case 11, which involves developing the capabilities of existing engineers E01 and E09 with respect to tasks associated with skills S08 and S12. In relation to the datum proposed project schedule, Case 11 corresponds to a 52 per cent reduction in the project's expected duration and a 45 per cent reduction in labour cost.

To establish if any further proposed changes to the team would result in reducing the project's expected duration, an analysis was performed on the proposed project schedule for Case 11, leading to the calculation of task duration-to-capability ratios for each skill. Figure 3 presents a comparison of task duration-to-capability ratios for Cases 2 and 11. While the imbalance in the project team has not been completely redressed, it can be seen that the most prominent discrepancies between the ratios for skills S08 and S12 have been reduced considerably.
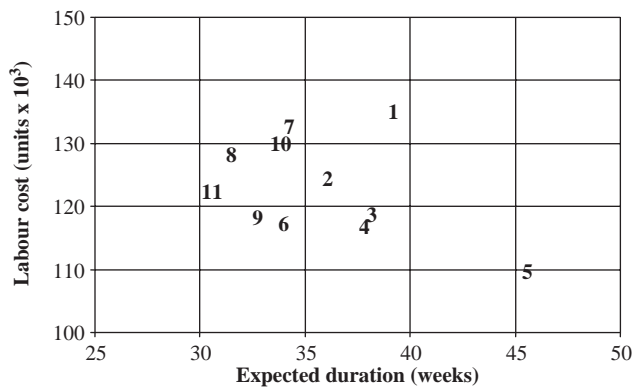

Fig. 2 Project's labour cost versus expected duration for Cases 1 to 11

In summary, as a result of excluding engineers' skill capabilities of 0.2 and less, and the proposed development of two existing engineers with regard to their capability to undertake tasks associated with two specific skills, it has been shown that the expected duration to complete the project could be reduced by 52 per cent with respect to the datum proposed project schedule. In addition, a labour cost reduction of 45 per cent could be achieved.

5 DISCUSSION

The case study provided by domnick hunter limited enabled an initial application of the preliminary approach. Prior to being introduced to this research, the organization had not considered quantifying their engineers' capabilities or modelling the project team in the manner proposed. While the method used to elicit measures of engineers' skills and capabilities is elementary, it did provide a basis for the organization to gain a quantified representation of its engineers' capabilities relative to the tasks to be undertaken, which could aid the planning of upcoming projects.

With a numerical representation of the engineers' capabilities in a range of skills, the GA and task-to-allocation strategy were used to generate a datum proposed project schedule. All nine engineers were allocated tasks in this schedule, but they were not allocated tasks associated with a skill for which they held a lower level of capability. As such, the exclusion of lower-level capabilities was proposed. Modelling the project team in this fashion showed that excluding engineers' capabilities of 0.2 or less
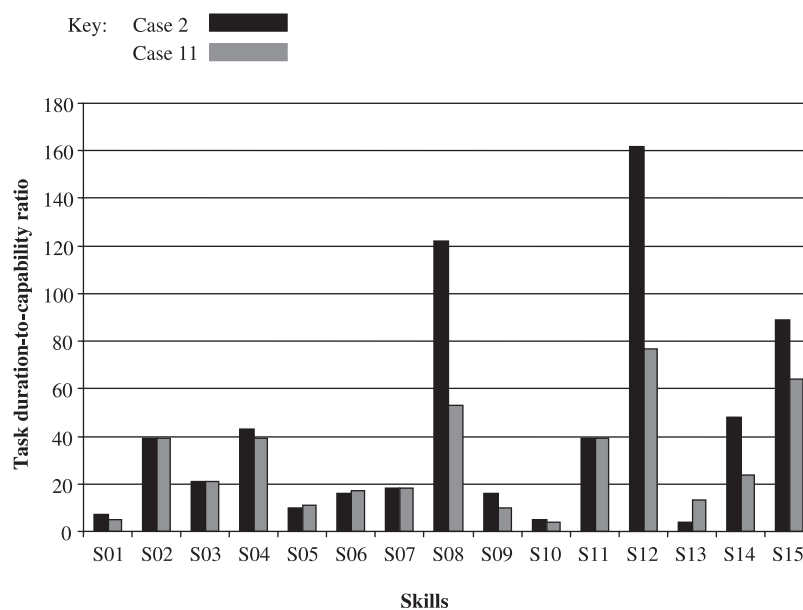

Fig. 3 Comparison of task duration-to-capability ratios for Cases 2 and 11

Table 7 Proposed model of the engineering design team's skills and capabilities

Engineer	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	S12	S13	S14	S15
E01	0.3	0	0	0	0	0	0	1.0	0.4	0	0	1.0	0.5	0	0.6
E02	0.9	0	0	0	0.5	0.5	0.5	0	0	0	0	0.9	0	0	0
E03	0.7	0	0	0	0.8	0.5	0.5	0	0.7	0.8	0	0	0.7	0	0.7
E04	0.5	0.9	0.9	0.9	0	0.5	0.3	0.7	0.5	0.6	0.8	0	0.5	0.8	0
E05	0.7	1.0	0.9	0.9	0.8	0.7	0.7	0.7	0.7	0.8	0.8	0	0.5	0.8	0
E06	0	0	0	0	0	0	0	0	0	0	0	1.0	0	0	0
E07	0.5	0	0	0	0	0.3	0	0.5	0.8	0.9	0	0	0.9	0	0.9
E08	0	0	0	0.3	0.3	0	0	0.3	0	0	0	0	0	0	0
E09	0.5	0	0	0	0	0	0.3	1.0	0	0	0	1.0	0	0	0

resulted in potential reductions of 44 per cent in the project's expected duration and labour cost with respect to the datum proposed project schedule. These potential reductions were offered since engineers with capabilities of 0.1 and 0.2 were prevented from being allocated tasks associated with the corresponding skill. Even with this proposed representation of the team, an imbalance existed in terms of engineers' capabilities in relation to project tasks. This imbalance was established using task duration-to-capability ratios derived from the proposed project schedules generated using the GA and task-to-engineer allocation strategy. In response to this imbalance, further to engineers' capabilities of 0.2 or less being ignored, changes to the composition of the project team were proposed, i.e. the development of existing engineers and recruitment of a new engineer. More specifically, two engineers were chosen to be developed since they were significantly underutilized in the proposed project schedule corresponding to excluding capabilities of 0.2 or less. The development of these two engineers involved increasing their level of capability from 0 to 1 in two particular skills. While the approach does identify in which skills the team is deficient, along with which engineers could be developed, it does not provide a means of specifying what level of capability would best be required in terms of reducing the project's expected duration and labour cost. As such, a value of unity was selected since this is the greatest value possible in the context of the approach. Further, the approach does not identify how an engineer could be developed so that their level of capability would increase. In terms of recruiting an engineer, the proposed change to the engineering project team's composition involved adding a person with a capability of unity in combinations of the two deficient skills. Again, a value of unity was chosen since it is the greatest value possible. An analysis of this proposed change to the composition of the project team, using the proposed project schedules generated, showed that developing two existing engineers so that they were able to complete tasks associated with the two deficient skills resulted in a 52 per cent reduction in expected duration and a 45 per cent reduction in labour cost. Further, the imbalance within the team of engineers was significantly redressed.

As a result of the application of the preliminary approach, the proposed skills and capabilities of engineers in the project team are shown in Table 7. Shaded cells indicate where proposed changes should be made with respect to the initial model of the engineering project team, which was shown earlier in Table 2. Therefore, the application of the approach has demonstrated potential in terms of modelling and planning the composition of an engineering project team, and identifying where proposed changes in the team's composition could be made and their effects in terms of reducing the project's expected duration and labour cost.

The company provided feedback indicating that the research offers a practical approach to modelling and managing the engineers in their R&D department. Further, it was noted that the research provides a useful technique for assessing their personnel requirements prior to starting projects involving their multidisciplinary, multiskilled engineering team. With regard to the significant reductions in the project's expected duration and labour cost, the company stressed that figures of the order achieved need to be realized for them to be successful in the future.

6 CONCLUSIONS AND FUTURE WORK

Engineering companies are constantly striving to enhance their current approaches to project management and introduce new approaches in order to improve performance and maintain competitiveness. Therefore, the research presented in this paper is timely in that it introduces a preliminary approach to modelling and planning the composition of engineering project teams. The approach has been applied retrospectively to an industrial project involving the design development of compressed air

treatment equipment. In this application, support has been provided in modelling and planning team composition in terms of engineers' skills and level of capability in these skills, in relation to the project tasks to be undertaken, using a GA and task-to-engineer allocation strategy. Further, the application has facilitated the identification of an imbalance in the team with respect to engineers' skill and capabilities given the tasks to be undertaken. Based on this imbalance, considered changes to the team were proposed and assessed, again using the GA and allocation strategy, in terms of expected duration to complete the project, engineer labour cost, and the degree to which any disproportion in the engineers' skills and capabilities has been redressed. Consequently, the exclusion of engineers' lower-level skill capabilities, along with the proposed development of two existing engineers with regard to two specific skills, led to a potential 52 per cent reduction in the expected duration to complete the project with an associated 45 per cent reduction in labour cost.

It is acknowledged that within the preliminary approach, some of the means used are simplistic in nature. However, the approach does provide a useful framework for further development; i.e. significant scope exists to develop more sophisticated means within the approach, such as how to identify the skills of engineers and, in particular, how to quantify the level of capability of engineers in the skills they have. Presently, the approach involves measuring skills in relation to the tasks to be undertaken. As such, in addition to consultation with project managers, a further means of identifying skills and quantifying capabilities may involve using questionnaires, assessment, and interviews with engineers in consideration of factors such as their practical experience, theoretical knowledge, previous performance, training, and qualifications. In addition, such a means should endeavour to take into account soft or interpersonal skills, such as those mentioned in section 2. However, it is acknowledged that this is a highly complex problem, which is widely recognized in the research literature.

The emphasis of the approach's application presented in this paper focused on the objectives of reducing the project's expected duration and labour cost. While it is acknowledged that these objectives are of great importance, it is also recognized that companies may have other objectives such as developing their personnel so that, in turn, the organizations and their teams can continuously improve performance in future projects and thus remain competitive. Therefore, in addition to using reduction in project duration to measure performance, other performance metrics and an appropriate means of measuring them should be researched. Further,

there is scope within the approach to develop task-to-engineer allocation strategies related to development at an individual and company level. The development of individuals would focus on broadening engineers' technical and interpersonal skills, and improving their capabilities. This could be realized in a number of ways such as shadowing proficient engineers, exposure to new and challenging work, and precision professional training. Indeed, Glen [35] recognizes that in today's highly competitive environments, it is of vital importance to support employees through providing them with experience-based development initiatives such as participation in key organizational projects. At a company level, broadening and improving the skill set of engineers would also result in reducing the vulnerability represented by people leaving the organization and taking key capabilities with them. Further, in terms of company development in relation to future projects, recruiting engineers with specific skills and capabilities not presently held within the organization would be a possible option for consideration.

Finally, while the industrial case study presented in the paper demonstrates an application of the preliminary approach to a single project, there is a need to seek further case studies involving multiple projects being undertaken concurrently. This will enable the approach to be developed to manage the complexities of resource contention in scenarios where skilled engineers are required to simultaneously work on several projects.

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