Job Assignment Based on Brain Demands and Human Resource Strategies

Alireza Ahmadian F. F.¹, Ali Akbarnezhad ², Taha H. Rashidi ³, S. Travis Waller ⁴

¹PhD Candidate, School of Civil and Environmental Engineering, Univ. of New South Wales, Sydney, NSW 2052, Australia (corresponding author). E-mail: ahmadian@unsw.edu.au

²Lecturer, School of Civil and Environmental Engineering, Univ. of New South Wales, Sydney, NSW 2052, Australia. E-mail: a.akbarnezhad@unsw.edu.au

³Lecturer, School of Civil and Environmental Engineering, Univ. of New South Wales, Sydney, NSW 2052, Australia. E-mail: rashidi@unsw.edu.au

⁴Professor and Director of the Research Centre for Integrated Transport Innovation (rCITI), School of Civil and Environmental Engineering, Univ. of New South Wales, Sydney, NSW 2052, Australia. E-mail: s.waller@unsw.edu.au

Abstract

Assignment of jobs to construction workers critically contributes to consistency of workload distribution. Inconsistent workload distribution may develop imbalanced fatigue rate within a crew that can cause inefficient and unsafe performance. In addition, improper assignment of tasks to workers may adversely affect human resource (HR) development within the organization through skill level stagnation, particularly for less-involved workers. To realize potential benefits of on-the-job training for HR development, a precise alignment between task planning and HR strategies is required. This paper proposes a systematic framework for job assignment to construction workers by considering workers’ capabilities, workloads, and HR strategies. The framework uses the outputs of a mathematical model that accounts for visual, auditory, cognitive, and psychomotor demands of the jobs. Maintaining safety, enhancing skill level, addressing aging problem, and/or multiskilling are integrated in the framework as the potential strategies to be considered when minimizing workload imbalances. Application of the framework is examined on a concreting case project in a simulation environment. Partial assignment of tasks is found to play a key role in smooth and practical implementation of the framework, with tangible impacts on workload distribution and throughput.

Keywords: Job assignment, construction crew, Brain resources, Human resource strategies
1. Introduction

Labour workforce plays a pivotal role in improving construction performance (Jergeas, 2010, Castañeda et al., 2003, Castaneda et al., 2005). To achieve utmost gain from construction workforce, the literature suggests a diverse range of models to identify the optimal crew allocation (Al-Bazi and Dawood, 2010, Hegazy and Wassef, 2001, Liu and Wang, 2007, Zhang et al., 2014). The proposed optimality is, however, limited to the crew size and composition at activity level, while tasks assignment boundaries within a crew are not modelled (Liu and Wang, 2012, Senouci and Eldin, 2004). On the other hand, improving task assignment practices has been targeted predominantly through applying techniques and methods which rely on advanced tools and technologies, such as information and visualization technologies, tracking systems, and modern equipment technologies (Caldas et al., 2005, Kang et al., 2007, Turkan et al., 2013). However, previous studies suggest that such techniques have been ineffective in improving utilization of labours, mainly due to great variabilities in utilization of different workers and poor management of their productive times (Gong et al., 2010, Peng et al., 2012, Thomas et al., 2002). Accordingly, detailed crew level planning has been hypothesized as a potential solution to address complications around task assignment (Gong et al., 2010).

A common approach to crew level planning is to match fineness of tasks and skill level of labours; that is, physically-demanding jobs are assigned to workers with the lowest skill level and the finest tasks are performed by the most experienced workers (Corominas et al., 2008, Trocine and Liu, 2008). However, such simplistic approach tends to overlook worker’s workload and human capacity, leading to likely workload imbalances and uneven fatigue rates among crew, which may put safety of workers at risk (Yates, 2014, SafeWorkAustralia, 2013). Moreover, long term execution of this strategy can widen the existing gap in the skill
level of workforce. This may ultimately worsen the shortage of skilled workers as a human resource (HR) management problem (Castaneda et al., 2005).

The importance of HR management strategies in planning real course of a construction project has been inadequately recognized in the literature, though it has been discussed from other angles (Ananthram and Chan, 2013, Becker and Smidt, 2016, Fulmer and Ployhart, 2014). The main streams in HR management have two features in common. First, the context, in which an issue is addressed, is typically isolated from daily interactions of the business. In other words, HR experts largely direct their attention to out of workplace (outward) solutions such as off-the-job training or external consultations (Kroll and Moynihan, 2015, OConnell, 1996). Overemphasizing on the external methods has been shown to be costly and time consuming (Rothbard, 1998, Swift and Nodine, 2013). Moreover, this approach may overlook the potential of in-house practices to resolve HR problems. Second, HR strategies are rather problem-oriented. While valuable quantitative analyses are usually performed on the identified problems, the resolutions mainly rely on qualitative suggestions of HR experts (McFillen and Maloney, 1986, Sroul et al., 2006). This may result in an inconsistent transition from a problematic situation to another in which no analytical assessment can be made on effectiveness of the proposed solutions.

Identifying these weaknesses in the literature about task assignment methods, this paper aims to provide a systematic framework for task assignment to workers by considering workers’ capabilities, workloads, as well as HR strategies. The proposed framework consists of two main phases. In the first phase, a mathematical model is used to analyse workers’ loads through accounting for brain resource requirements of the jobs. In the second phase, HR strategies are integrated into job assignment process as the main governing rules to balance the workloads. The proposed framework also contributes to the body of knowledge through presenting an algorithm which directs the adjustments required in job assignment process to
simultaneously satisfy HR strategies in a project and minimize workload differences among workers. Application of the proposed framework is illustrated through a task assignment exercise in a real world concreting project. The effectiveness of the model is examined using performance data of the case project as well as historical records of the contractor in similar operations. Further, the potential of adjusted job assignments in realizing their intended targets are studied in Discrete Event Simulation (DES) environment.

2. Literature Review

The allocation of human resources to construction activities has been highlighted in previous studies as a complex problem (Fan et al., 2012). The complexity of the problem stems from a diverse range of real world constraints, including schedule obligations, budget limitations, technical requirements, and availability of resources, that are required to be satisfied concurrently (Callahan et al., 1992, El-Rayes and Moselhi, 2001, Harris and Ioannou, 1998, Hegazy et al., 2000, Hegazy and Wassef, 2001, Liu and Wang, 2012). Accordingly, the optimal solutions are supposed to provide information on crew size and composition, as well as start and finish times of activities (Callahan et al., 1992, Long and Ohsato, 2009). In a real world situation, however, implementation of an activity relies on a more detailed plan in which assignments of individuals are also considered in planning.

An approach to a detailed execution plan, commonly advocated by Construction Industry Institute (CII, 2013) and Construction Owners Association of Alberta (COAA, 2014), is workface planning (WFP). WFP is a set of practices that are put in place to ensure a craft person is supplied by adequate elements required for a job; such as materials, tools, and drawings, and the job is performed in an effective and safe manner (Siu et al., 2016). Nevertheless, this approach dose not explicitly take mental and physical requirements of a job into considerations. To accommodate job characteristics into the planning process, a primary approach is to categorize workers into groups of physical and fine (Corominas et al., 2008,
Trocine and Liu, 2008), which are respectively allocated to physically and mentally-demanding jobs, without accounting for the effects of such categorisation on development of HR. An advanced form of this approach, however, assigns tasks by taking human characteristics into considerations (Baines and Kay, 2002, Lockett, 1997). The fundamental objective in this approach is to ensure that operation of a system is efficient, while the system maintains human needs. Therefore, factors such as workers’ specialty and proficiency, morale, training, errors, and sleep needs are taken into the design (Trocine and Liu, 2008).

This has further led to attention towards shift and rest time design in various operations, particularly with a factory-production nature (Kogi, 1996, Koller, 1996, Sheahan et al., 2016). The study performed by Alvanchi et al. (2012) on physical and mental fatigue of a crew, as a whole, in a pipe spool fabrication shop is an extension of system design research to a construction operation. The work combines physical fatigue rates, which is based on consumable energy of human body, with mental fatigue rates, which is based on hypothetical percentiles for mental resources.

Scientists of medical research have shown that fatigue, and hence the need to rest, can be described solely by brain activities (Hall and Guyton, 2011). Through disconnecting the torso of animals from their head, the experiments on a tired body showed that lower mechanisms of the body work normally without being under executive control of the higher structure. Therefore, it has been concluded that the brain triggers fatigue and the need for a rest (Knutson et al., 2007, Mollayeva et al., 2014, Noakes, 2012). This seems to be the fundamental principle for corresponding workload balance to components of brain resources in military laboratories in the US (McCracken and Aldrich, 1984, Mitchell, 2009). Unlike previous studies in which workload of an operation is measured as a whole and through a subjective analysis, studies conducted by the US military laboratories decompose an operation into its constituting tasks which are then analysed using a set of predefined scales.
The predefined scales are mainly from the model conceptualized by McCracken and Aldrich (1984) in which brain is considered to consist of four types of resources, namely visual, auditory, cognitive, and psychomotor (VACP).

Optimizing the workload, on the other hand, has been stipulated as an objective in International Organization for Standardization 10075, an international standard for ergonomic principles (Nachreiner, 1995). This situation is defined by Hart (1991) as a point “in which the operator feels comfortable, can manage task demands intelligently, and maintains good performance”. In other words, optimality of worker’s performance was found to be correlated with an acceptable level of workload that is neither high nor low. Consequently, performance of a crew, as a whole, is enhanced when the overall workload is distributed amongst its individuals, evenly, by considering the capabilities of individual workers.

Apart from its intrinsic effect on performance, workload may also influence learning capacity of individuals. According to cognitive load theory, which was originally hypothesized and proved in the education science, there is an association between load of tasks and learning structure (Sweller et al., 2011). The theory rationalises this relationship based on the limited capacity of working memory (Miller, 1956). Therefore, an impeded learning rate is predicted when a person is overloaded. On the other hand, effect of learning on improving performance has been widely acknowledged by previous studies (Anzanello and Fogliatto, 2011). The learning effect is formulated through reduced time or cost caused by repetition in performing similar units of work. This effect has been reported to be perceptible from simple construction activities (Malyusz and Pem, 2013, Thomas et al., 1986) to complicated official processes (Wong et al., 2010, Zhang et al., 2014). Nevertheless, little has been done to proactively take advantage of this effect in crew selection and task planning. In particular, personal differences in a crew, especially those attributable to age and experience (Biskup,
2008, Clark et al., 2015), can be taken to stimulate advantage of learning, provided that an appropriate strategy is systematically employed.

HR is commonly considered as the most important asset for construction entities (Fulmer and Ployhart, 2014). Reliability of this asset is, however, dependent on a number of factors, most notably, safety and productivity (Becker and Smidt, 2016, Thomas, 1991). Although there are numerous factors contributing to productivity, skill level of workers is unconditionally related to this issue (De Bruecker et al., 2015). Therefore, maintaining workforce’s skill at an acceptable level is generally a strategic priority for major firms (Fulmer and Ployhart, 2014, Khanmohammadiotaqsara et al., 2012). The aging of the workforce is an obstacle to a productive team. This has drawn the attention of HR scholars to young inexperienced workers for a smooth transition from an aging skilful workforce (Ciutiene and Railaite, 2014, Morton et al., 2005). Alternatively, multiskilling has been suggested as a solution to skill shortage problem (Burleson et al., 1998, Chini et al., 1999). To cope with the aforementioned factors, training is recommended as a general solution and its promoted scheme is off-the-job (OConnell, 1996). Even so, concerns with effectiveness and cost of an isolated training program have persuaded HR specialists to launch investigations about on-the-job training (Rothbard, 1998, Swift and Nodine, 2013). On-the-job training is specially challenging in the construction context and requires a planning framework to make it in-line with the operational activities and task assignment process. If properly organized, this can concurrently benefit HR development and overall performance.

3. Framework architecture

The proposed platform consists of two main components. The first component uses a mathematical model to account for brain resource requirements of tasks in the job assignment process. The second component details human resource (HR) strategies that are aimed to be integrated into the job assignment process. An algorithm is suggested here for both
components to interactively contribute to an objective function which targets to evenly
distribute jobs across all workers.

3.1. Mathematical model

3.1.1. Basic parameters

i denotes the primary skill set of a single-skilled or multi-skilled worker. For instance, the
skill sets required in a concreting operation include “reinforcement iron-working”,
“carpentry”, and “pouring, curing, and finishing” of concrete. These three primary skill sets
are denoted by i=1, 2 or 3, respectively.

The skill level of the worker is denoted by e. As suggested by previous studies, the years-of-
experience is used as the main indicator of skill level (Majozi and Zhu, 2005, De Bruecker et
al., 2015). Using pre-defined lower and upper limits for each skill level category, workers are
grouped into three levels in which e=1 denotes a young helper (0-6 years of experience), e=2
represents a journeyman or a standard worker (7-15 years of experience), and e=3 denotes a
highly-experienced (16-25 years of experience) worker.

B_e denotes average years of experience in category e of skill level.

z is a binary parameter taking the value of 0 if the worker is single-skilled and 1 otherwise. In
this study, the four-skill strategy, indicating the capability of a multi-skilled worker
possessing all the skill sets required to undertake its relevant construction operation, is
adopted (Burleson et al., 1998). In case of a concreting operation, hence, a certified concreter
is taken as a multi-skilled worker who is able to perform all reinforcing, carpentry, and
concrete finishing jobs as specified by (Licensedtrades, 2014).

j denotes the type of the activity taking positive integer numbers. Types of activities are
defined depending on classification strategy. While a planner may use a skill-dependent
definition of activities, such as “steel reinforcement activity”, it is also possible to consider an
element-based approach, where construction of a particular element, e.g. “construction of a
column”, is considered in categorizing activities.
m denotes a task involved in undertaking an activity and takes numbers starting from 1.

3.1.2. Main Parameters

(a) Productivity

Productivity of a worker can be recorded in real time as “duration of performing a definite
quantity of a task”. In the absence of such data, particularly when a worker performs a newly
assigned task, an estimation method is required. Accordingly, productivity of a worker who
possesses skill i, from experience category e which belongs to subgroup n, and with
multiskilling status z, when performing task m in activity j is given by \( p_{j \text{mrez}} \) and is estimated
as:

\[
 p_{j \text{mrez}} = \frac{p_{j \text{m0}}}{FA_z \times FA_e \times FA_r}
\]

where \( p_{j \text{m0}} \) is the initial productivity of a novice worker in doing task m in activity j as
indicated by the historical data. FA\(_z\), FA\(_e\), and FA\(_r\) are factors that account for the effects of
multiskilling, experience, and learning, respectively.

FA\(_z\) indicates expected improvement in productivity of the multi-skilled workers compared
with single-skilled workers and is formulated as follows:

\[
 FA_z = \begin{cases} 
 > 1 & \text{if } z = 1 \\
 = 1.0 & \text{if } z = 0 
\end{cases}
\]

The magnitude of improvement has been estimated in an empirical study to be 15% for a
multi-skilled crew (Rodriguez, 1998). While considerably higher values are assumed by
previous studies (Liu and Wang, 2012), there is a lack of consensus about achievability of
such level of improvements in practice (Srour et al., 2006). Therefore, a conservative
stochastic value of up to 15% is assumed for this factor in this study.

Equation 3 accounts for the effect of past experience in a similar task through Stanford-B
equation of learning theory (Anzanello and Fogliatto, 2011):
\[ FA_e = \begin{cases} \left(1 + B_{en}\right)^{R_j^m} \times \left(\Delta B_{en}\right)^{G_j^m} & \text{if } (i = j \text{ and } m \text{ is currently or had been previously performed by } n) \\ 1.0 & \text{if } i \neq j \text{ or if } (i = j \text{ and } m \text{ has never previously been performed by } n) \end{cases} \] (3)

In the top right side of equality, the equation has two parts. The first left parenthesis represents improved performance resulted from the years of past experience (Be) through experience rate of \( R_j^m \) and is solely sufficient if the worker is currently performing the same task. The second parenthesis of this equation includes possible forgetting effects through \( \Delta B_e \), as the forgetting period, and \( G_j^m \), as the forgetting rate (Anzanello and Fogliatto, 2011). This secondary factor is applicable to a worker with previous experience in doing task \( m \) involved in activity \( j \), but hasn’t done this task for a specific period. An instance is a worker who belongs to the highest experience category, currently doing supervisory tasks, but has been reassigned to help with a non-supervisory task that s/he had performed in the past when s/he belonged to a lower experience category. The values of \( R_j^m \) and \( G_j^m \) should be estimated using long-term historical data on performance records in a specific task.

On the contrary, a temporary learning effect may be observed over the course of implementation. This effect is taken into account through \( FA_r \) parameter, which can be calculated using following equation:

\[ FA_r = (u)^{m_{izen}} \] (4)

where \( u \) is the unit of work to be performed, and \( r_j^{m_{izen}} \) is the learning rate of task \( m \) in activity \( j \) for a worker who possesses skill set \( i \), with multiskilling status of \( z \), and from experience category of \( e \) in subgroup \( n \). The learning rate of a worker can be defined by the following function:

\[ r_j^{m_{izen}} = f(m \notin n, z, e, R_j^m) \] (5)

This function presumes that the temporary learning rate of a worker in a task depends on the complexity of new skill, if any, to be learnt, his/her multiskilling status, and years of
experience. Based on cognitive load theory, it is also assumed that the temporary learning rate of a worker is negatively influenced by an increase in the brain load (Sweller et al., 2011).

b) Crew formation

On the other hand, size of the subgroup “n” within the crew allocated to activity j is denoted by $y_j^n$ and is computed as follows:

$$y_j^n = \sum_i \sum_z \sum_e x_{izen} \quad \forall \ i, z, e \subset n$$  \hspace{1cm} (6)

The crew allocated to activity j, $y_j$, is then given by:

$$y_j = \sum_n y_j^n \quad \forall \ n \subset j$$  \hspace{1cm} (7)

Further, Y is the total number of crews allocated to the whole project and is computed by:

$$Y = \sum_j y_j$$  \hspace{1cm} (8)

c) Brain load of tasks

In this paper, we use the brain loads associated with tasks to improve job assignment process.

To perform a task four types of brain resources, namely visual, auditory, cognitive, and psychomotor, may be required. Therefore, performing a task may impose corresponding types of brain loads to a worker’s brain and is computed as follows:

$$l_j^{izen} = a_j^m + \beta_j^m + \gamma_j^{izen} \times (y_j^{izen} + \lambda_j^{izen})$$  \hspace{1cm} (9)

where $l_j^{izen}$ is the total brain load per cycle of task m in activity j assigned to a worker who belongs to skill set i, with multiskilling status z, from experience category e in subgroup n. Auditory, visual, cognitive, and psychomotor loads are respectively denoted by $a_j^m$, $\beta_j^m$, $\gamma_j^{izen}$, and $\lambda_j^{izen}$. While the first two brain load components depend solely on nature of the task itself, the last two may need to be adjusted depending on likely previous experience of the worker in performing that specific task. As a worker gains experience, s/he may develop an appropriate strategy that can help in reaching an autonomous level in managing cognitive and psychomotor brain resource requirements of a task (Alonso et al., 2014, Mitchell, 2009).
This will lead to a reduction in the cognitive and psychomotor components of the brain load which is taken into account using the following coefficient:

\[
S^m_{ij} = \begin{cases} 
1 & \text{if } z = 0 \text{ and } (i \neq j \text{ or } m \notin n) \\
< 1 & \text{otherwise}
\end{cases}
\] (10)

This coefficient can be empirically related to a worker’s experience and his/her autonomous decision making level in a specific task (Alonso et al., 2014, Mitchell, 2009).

To compare job assignments of different subgroups within an activity on the same par, a daily normalized load for each subgroup is calculated. Therefore, quantity of the work performed daily and size of corresponding subgroup should be taken into account as follows:

\[
L^m_{jn} = \frac{q^m_{jn}}{\bar{q}^m_{jn}} \times \sum_{l} l^m_{ij} S^m_{ijn}
\] (11)

Where, \(L^m_{jn}\) is the daily brain load incurred by subgroup \(n\) when performing a daily quantity of task \(m\) equal to \(q^m_{jn}\); and \(\bar{q}^m_{jn}\) is quantity of task \(m\) in each cycle. Thereafter, a daily workload index over all the tasks within activity \(j\) assigned to subgroup \(n\), \(WL^j_n\), is computed as follows:

\[
WL^j_n = \sum_{m_n} L^m_{jn} \quad \exists m_n \in \{m\}, \forall j
\] (12)

To balance workload, differences amongst subgroups should be minimized. Therefore, an average workload index, \(\bar{WL}_j\), is calculated initially for the whole crew allocated to activity \(j\):

\[
\bar{WL}_j = \frac{\sum_n WL^j_n}{y_j} \quad \forall n \subset j
\] (13)

The difference between the computed index for a subgroup and the average workload index; \(WL^j_n - \bar{WL}_j\); can then determine whether or not a subgroup is overloaded. In other words, positive and negative values represent overloaded and underperforming teams, respectively.

Through analysing the workload status of various subgroups within a crew, workload imbalances are identified.

Imbalances within a crew is then indicated by computing the workload variance, \(\sigma^2_{\bar{WL}_j}\), or its standard deviation, \(\sigma_{\bar{WL}_j}\).
Minimizing the standard deviation is set as the objective function in the job assignment process performed to workers within a crew:

\[
\sigma_{WL_j} = \frac{\sum_n (WL^n_j - WL_j)^2}{y_j} \quad \forall \; n \subset j
\]  

The optimization process is subject to maintaining a predetermined level of performance for the crew, which can be defined in terms of an overall output rate for the activity \( j \).

In addition to workload balance within a crew allocated to an activity, balanced job assignments to workers can be targeted for the project and across different crews. Therefore, the formulations are supplemented by calculating average workload of the whole workforce, \( WL \), as follows:

\[
WL = \frac{\sum_j WL_j}{Y} \quad \forall \; n \subset j
\]  

Job imbalances are then represented by calculating workload variance amongst the project workforce, \( \sigma^2_{WL} \), or its standard deviation, \( \sigma_{WL} \):

\[
\sigma^2_{WL} = \frac{\sum_j (WL_j - WL)^2}{Y} \quad \forall \; n \subset j
\]

\[
\sigma_{WL} = \sqrt{\frac{\sum_j (WL_j - WL)^2}{Y}}
\]

Consequently, the job assignment process is balanced at the project level by:

\[
\therefore \; \text{minimize} \; \sigma_{WL}
\]

Apart from aforementioned performance constraints that may be applied to optimization of workload distribution among workers, the optimization process is strategically governed by human resource policies. This can add a long-term perspective to planning stage of activities. The effect of these policies on the optimization process is described in section “HR wing”.

### 3.2. HR component: accounting for human resource policies in job assignment

Four HR strategies that can be accommodated into day-to-day workforce performance are “safety improvement”, “skill enhancement”, tackling “aging problem”, and “multiskilling”
To account for objectives of a HR strategy in the optimization of daily workload formulated in section 3.1, each strategy is used to direct modifications in the initial job assignment process as described in the following:

3.2.1. Original approach in job assignment

Figure 1.a shows the original approach in job assignment to workers within a crew. This job assignment process is preceded by a crew allocation stage which is performed either through optimization models or via planning techniques (Ahmadian F F et al., 2015, Hassanein and Melin, 1997, Hegazy et al., 2000, Liu and Wang, 2007). In this process, the crew allocated to an activity is assumed to possess the skill set required for the activity unless the multiskilling strategy is implemented (Burleson et al., 1998).

Tasks involved in the activity are initially (traditionally) divided into three categories: physical, fine, and supervisory tasks. Respectively, the crew is split into three subgroups. The physical tasks are assigned to a subgroup whose members are supposed to be the least experience workers with physical strength, and may be called “juniors”. Fine tasks are mentally-demanding jobs assigned to a group of standard workers who have higher experience compared to the first group and are commonly called “journeymen” in the relevant literature (Gong et al., 2010). The supervisory tasks demand for the highest level of experience and are assigned to a group of “foremen”.

3.2.2. HR strategy 1: safety improvement

To maintain safety of workers, they are assigned to tasks that are closer to their past experience. Therefore, the workload (brain load) differences are minimized while defining “shared tasks” within an activity in which workers from different categories can cooperatively perform the jobs. As shown in Fig 1.b, these tasks are those at the border of each task category, i.e. physical, fine, supervisory, which may require a combination of skill
subsets to be undertaken by a worker. For instance, a worker who is primarily assigned to fine tasks can also help with marginally physical jobs in order to reduce the brain load of juniors, if they are identified as the overloaded group. Similarly, when journeymen are overloaded, a physical worker may be involved in a simple fine task with a significant physical feature to balance the workload. This reform in job assignment process and its subsequent workload balance may be achieved through partial assignment of a task to a subgroup. The ratio of a task assigned to a subgroup is then calculated as follows:

$$K_j^{mn} = \frac{q_j^{mn}}{q_j^m}$$  \hspace{1cm} (21)

Where, $q_j^{mn}$ and $K_j^{mn}$ are respectively the daily quantity and the ratio of task $m$ in activity $j$ assigned to subgroup $n$, and $q_j^m$ is the total daily quantity of this task to be performed. The rule of partial assignment is also applicable when implementing other strategies and simultaneously ensures a young worker is always supervised by a more-experienced one.

3.2.3. HR strategy 2: skill enhancement

Figure 1.c outlines implementation of skill enhancement strategy. Under this strategy, breaking the boundaries between different subgroups of a crew is allowed in order to balance the load. Therefore, new job assignments are less constrained by past experience of workers in doing a specific category of tasks within an activity. For instance, workers with lower skill level in an activity are not just limited to physically demanding jobs but rather permitted to take part into fine tasks and their workload modification may be achieved through partial involvement of them in mentally demanding jobs. The same approach can be adopted to concurrently balance the load of journeymen and to train them for supervisory jobs, as shown in Figure 1.c. The degree of skill enhancement of a subgroup depends on the ratio of the task, i.e. $K_j^{mn}$, partially assigned to the subgroup. The higher the ratio is, the greater degree of skill enhancement is expected to be achieved.

3.2.4. HR strategy 3: addressing the aging workforce problem
To address the problem of aging experienced workforce, who are traditionally (originally) allocated to complex and fine tasks of activities, job assignments are revised so that a specific proportion of finer and more sophisticated tasks are assigned to young inexperienced workers. As shown in Figure 1.d, the overall outline of this strategy is similar to skill enhancement. However, the emphasis is put on the first subgroup, which is assumed to be formed by young physical workers. Therefore, the optimization of workload is targeted mainly through partial engagement of young workers into jobs assigned to older subgroups.

3.2.5. HR strategy 4: multiskilling

In this strategy, boundaries of assignments are extended so that the job assignment process goes beyond existing practice that limits subgroups within their own crew and its skill set. Unlike previous strategies in which workers are primarily supposed to possess a skill set corresponding to a specific activity, multiskilling,
d) Addressing aging problem strategy

Figure 1. Boundaries of task assignment before and after integration with human resource strategies: a) original task assignment, b) safety improvement, c) skill enhancement, d) aging problem, and e) multiskilling particularly the four skill strategy, do not restrict job assignment and workload optimization processes to agreement between skill set and activity requirements (Burleson et al., 1998). For instance, formwork erection crew is allowed to be allocated to tasks involved in steel reinforcement activity in a concreting operation.
Figure 2. Algorithm for assignment of jobs by considering brain resource demand of tasks and workers capabilities directed by a HR strategy

3.3. Job assignment algorithm

To integrate human resource strategies into job assignment process, the algorithm shown in Figure 2 is established. This algorithm is built on the brain resource demands of the jobs and
workers’ capabilities in the planning phase of a construction project. The process constitutes five main consecutive steps as described below.

First, the framework starts with a crew composition allocation for different activities of a project which can be ideally achieved through an optimization model. In this step, project constraints including activity relationships, resource availability constraints, and crew size and site congestion limitations are considered in the optimization process. The results consist of activity start and finish dates, crew size, and crew composition in terms of skill, skill level, and multiskilling status. The optimization model used in this stage has been previously developed and reported by the authors and detailed description of formulations used is not in the scope of this paper (Ahmadian et al., 2015). In addition to optimization methods, crew allocation can be simply concluded using available planning techniques.

Second, activities are decomposed into their tasks and subgroups of a crew are initially formed. Initial formation of subgroups is mainly based on skill level in which three categories of helpers, journeymen, and foremen represent lowest to highest experience levels, respectively. Likewise, tasks are preliminary divided into three similar categories of physical, fine, and supervisory (or the finest) and are assigned to each corresponding subgroup.

<table>
<thead>
<tr>
<th>Type</th>
<th>Scale</th>
<th>Value</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td></td>
<td>1</td>
<td>Monitor, Scan, Survey</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Detect movement, change in size, change in colour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Track, Align, Orient on</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Discriminate symbols, objects/ Read text</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Discriminate based on multiple aspects</td>
</tr>
<tr>
<td>Auditory</td>
<td></td>
<td>1</td>
<td>Detect occurrence of sound, tone, etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Detect change in amplitude, pulse rate, pitch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Comprehend semantic content of message</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Discriminate sounds on the basis of signal patterns, pitch, pulse rate, amplitude</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Cognitive</td>
<td></td>
<td>1</td>
<td>Automatic (Stimulus response)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Recognition of an element, job, process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>Encoding/decoding, recall! Alternative selection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>Formulation of plans/ (Projecting action sequence, etc.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>Evaluation (Consider several aspects in reaching judgement), estimation, calculation, conversation</td>
</tr>
</tbody>
</table>
Third, each task is analysed based on its main actions and the workload associated with each task is computed based on the scales defined for different types of brain resources required for the actions involved. In this study, the scales are adopted from the VACP model developed by (McCracken and Aldrich (1984)), with minor modifications to ensure their compliance with the conditions of a concreting operation as shown in Table 1. On the other hand, duration (cycle time) of each task is required to be linked to the computations of daily brain loads. This duration can be estimated either using Equation 1 presented in section 3.1 of the proposed framework or using the data collected from site observations.

Forth, the effect of potential strategies on brain resource requirements is estimated using Equation 10. Further, equations 9 to 12 are established to compute daily workloads of different subgroups. Therefore, workload indexes are computed using equations 13 to 15. Accordingly, overload and underload subgroups are identified.

Finally, HR strategies are integrated into the task assignment process. Depending on the HR strategy; the potential tasks, which can be cooperatively performed by different subgroups, are selected. Subsequently, the partial assignment of the selected tasks to the identified subgroups is iteratively manipulated until a balanced workload within the whole crew is reached and Equation 16 is minimized. It should be noted that the optimization of job assignment must also meet the planned daily output rate for the crew. While HR strategies mainly adjust job assignments within the boundaries of an activity, multiskilling penetrates into different activities and may necessitate change in crew size and composition, leading to need for a new crew optimization process.

Table 2. Workers’ characteristics and crew composition under single skill and multiskilling modes

<table>
<thead>
<tr>
<th>Primary Experience</th>
<th>Multi- Learning</th>
<th>Single skill mode</th>
<th>Multiskilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discrete actuation</td>
<td>Discrete adjustment and actuation</td>
<td>Continuous actuation</td>
<td>Continuous adjustment and actuation</td>
</tr>
<tr>
<td>Manipulative actions (Handling multiple objects and tools concurrently, controlling machinery, etc.)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Case study

A concreting operation in a three storey residential building project, with an underground parking, located in Melbourne, Australia, is considered as a demonstrative case study. The contractor has initially formed three single-skilled crews corresponding to “steel reinforcement”, “formwork and scaffolding erection”, and “concrete pouring and finishing”.

<table>
<thead>
<tr>
<th>Skill set</th>
<th>category</th>
<th>skilled status</th>
<th>index</th>
<th>Steel Reinforcement crew</th>
<th>Carpentry and scaffolding crew</th>
<th>Concreting crew</th>
<th>mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Helper</td>
<td>Journeyman</td>
<td>Foreman</td>
<td>Helper</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>(Ironworker)</td>
<td>0</td>
<td>0.9-1</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>(Carpenter)</td>
<td>0</td>
<td>0.7-08</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>(Concreter)</td>
<td>1</td>
<td>0.4-05</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Consult Drawings → Handle Materials → Cut → Bend → Position → Tie → Chair → Inspect

439

a) Steel reinforcement
Figure 3. Workflow of a) steel reinforcement b) formwork erection c) concreting and a snapshot of simulation models activities, as shown in Table 2. Formation of crew is guided through the methodology presented in Hassanein and Melin (1997), given 2475 m² total area of this project for a planned duration of 57.5 days. As can be seen, three originally formed subgroups in each crew are “helpers”, “journeymen”, and “foremen”. As defined in the relevant literature (Corominas et al., 2008; Trocine and Liu, 2008); in general, purely physical tasks are assigned to helpers, fine tasks are to be performed by journeymen, and foremen are made responsible for supervisory and mindful jobs. Formation of these subgroups is mainly assumed based on experience category of workers as the basic indicator of skill level (De Bruecker et al., 2015). In other words, helpers and foremen are the least and most experienced people, respectively. Activities and tasks involved in each are given in the left
two columns of Table 3. Table 4.a presents the details of tasks assigned to each subgroup within a crew before application of the proposed framework. Moreover, workflows of the activities, as simulated in Simphony software, are shown in Figure 3.

4.1. Project parameters

In this paper, the productivity data collected from case project during twelve days, 651 observations, are used. Table 3 summarizes cycle times normalized using minimum meaningful quantity of works corresponding to an activity. These quantities are approximately equivalent to 0.1 m³ of a concreted element. Alternatively, one may use historical performance data, subject to availability. In this case, Equation 1 should be used to compute cycle times. When cycle time data are available, this equation may be also used to estimate productivity of a worker in a newly assigned task through back calculation.

Table 3 shows the brain loads associated with performing tasks. These loads have been estimated by a joint team of project planners and the authors with reference to the scales defined in Table 1. We assumed a stochastic uniform range, when the conditions of doing a task can be placed somewhere in between two limits. The values reported in brackets, however, represent an autonomous level of action in a respective task, if applicable.

On the other hand, learning rates, at activity level, are extracted from past historical performance data of the contractor, recorded over five years in three projects located in the same territory with relatively similar scope, size, and complexity. As seen in Table 3, these rates vary between a minimum and maximum for each task. The learning rates for tasks have been estimated based on the overall rates of the activity and the complexity of each task with respect to other tasks involved in that activity as rated by experts. A higher rate assigned to a task explains its greater contribution to the complexity of its corresponding activity, as judged by the project experts. Skill learning rates required to estimate experience effect, in Equation 3, are considered as deterministic values and assumed to be 87%, 90%, and 95% for steel
reinforcement, carpentry, and concreting jobs, respectively. Correspondingly, forgetting effects are taken as 13%, 10%, and 5% (United Nation Housing Committee database).

Moreover, a learning index between 0 and 1 is assigned to each worker based on Equation 5, as shown in Table 4. The stochastic range considered changes during a day. In this approach, the maximum value is associated with fresh start, while assuming a linear decrease in the value with an increase in the daily brain load, as suggested by cognitive load theory.

### Table 3. Cycle time, brain load, and learning rate of tasks involved in each activity

<table>
<thead>
<tr>
<th>Activity (j)</th>
<th>Task (m)</th>
<th>Cycle time¹ (min) (average, standard deviation)</th>
<th>Brain load</th>
<th>Learning rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Visual/ Auditory</td>
<td>Cognitive</td>
</tr>
<tr>
<td>1 (Steel Reinforcement per 20 kg=0.1m³)</td>
<td>1 (Consult Drawing*)</td>
<td>2.025</td>
<td>4</td>
<td>2-3[1-2]</td>
</tr>
<tr>
<td></td>
<td>2 (Handle Material)</td>
<td>2.83, 0.45</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3 (Cut)</td>
<td>1.07, 0.21</td>
<td>3</td>
<td>2-3[1]</td>
</tr>
<tr>
<td></td>
<td>4 (Bend)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>big size (&gt;=10)</td>
<td>2.03, 0.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>small size (&lt;10)</td>
<td>1.41, 0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 (Position/ Install)</td>
<td>2.07, 0.49</td>
<td>3</td>
<td>2-3[1]</td>
</tr>
<tr>
<td></td>
<td>6 (Tie)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (Chair*)</td>
<td>1.6, 0.4</td>
<td>2</td>
<td>3[1]</td>
</tr>
<tr>
<td></td>
<td>8 (Inspect*)</td>
<td>1.4, 0.21</td>
<td>1</td>
<td>5[1-2]</td>
</tr>
<tr>
<td>1 (Consult drawing*)</td>
<td>2.025</td>
<td>4</td>
<td>2-4[1-2]</td>
<td>0-1</td>
</tr>
<tr>
<td></td>
<td>2 (Handle material)</td>
<td>3.52, 0.54</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3 (Mark and Cut)</td>
<td>2.61, 0.33</td>
<td>3</td>
<td>3-4[2]</td>
</tr>
<tr>
<td>2 (Formwork and Scaffolding; per 0.1m³)</td>
<td>4 (Install)</td>
<td>2.5, 0.56</td>
<td>3</td>
<td>2-4</td>
</tr>
<tr>
<td></td>
<td>5 (Nail)</td>
<td>4.21, 0.69</td>
<td>3-4/2</td>
<td>2-3</td>
</tr>
<tr>
<td></td>
<td>6 (Slab and beam)</td>
<td>2.23, 0.28</td>
<td>2-3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>(Support*)</td>
<td>4.05, 0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7 (Fix Joists*)</td>
<td>2.9, 0.19</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>8 (Install handrail*)</td>
<td>1.1, 0.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 (Concrete pouring and finishing; per each 0.1m³)</td>
<td>1 (Assemble accessories)</td>
<td>5.16, 0.75</td>
<td>3-5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2 (Pour)</td>
<td>1.2, 0.15</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3 (Slab and Beam)</td>
<td>1.8, 0.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Compact)</td>
<td>0.52, 0.13</td>
<td>1</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>4 (Finish)</td>
<td>0.78, 0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.08, 0.58</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Cycle times are reported in the form of the average and standard deviation at a normal distribution.
2. Values reported in bracket represent an autonomous level that an experienced worker may develop.
3. Tasks with an asterisk are not performed in every sequence (cycle) of an activity.

4.2. Results and discussions
The simulation run settings were adjusted for 100 runs, in a day of eight working hours (excluding the rest times). Table 4.a shows simulation statistics for the case where performance data are collected from original job assignment mode. The validity of simulation models was confirmed by compliance of average throughputs statistics with quantities reported by the contractor. Average production rates are 137.1 kg/h, 8.27 SMCA (square meter contact area)/h, and 5.82 m³/h in steel reinforcement, formwork erection, and concreting, respectively.

As shown in Table 4.a, the conservative approach that limits workers to “suitable-to-experience” jobs led to a significant brain load difference, ranging from 88.65 in concreting to 147.28 in steel reinforcing. This develops high brain load imbalances and hence, uneven fatigue rates within a crew, while their daily rest times are identical. With this in mind, some workers are expected to experience brain overloads. An overloaded brain, however, is a source of hazard (Mitropoulos and Memarian, 2012) that can neutralize risk-averse assignment of jobs initially adopted.

<table>
<thead>
<tr>
<th>Crew (i)</th>
<th>Subgroup (n)</th>
<th>Tasks Originally Assigned</th>
<th>Brain load differences (σ̅WL_j)</th>
<th>Average Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2,3,4,5</td>
<td>147.28</td>
<td>137.1 kg/h</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1,6,7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1,8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2, 4, 6</td>
<td>93.90</td>
<td>8.27 SMCA/h⁴</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1, 3, 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1, 7, 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1, 2</td>
<td>88.65</td>
<td>5.82² m³/h</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2, 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3, 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crew (i)</th>
<th>Subgroup (n)</th>
<th>Integrated HR strategy</th>
<th>New partially assigned tasks</th>
<th>Minimum brain load differences (σ̅WL_j)</th>
<th>Average Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>Maintaining Safety</td>
<td>6</td>
<td>31.61</td>
<td>142.3 kg/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5, 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Skill Enhancement</td>
<td>3</td>
<td>56.40</td>
<td>8.38 SMCA/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Assignment of tasks to workers, their brain loads differences, and average throughput
To moderate brain load differences, job assignment was reinitiated in each activity using the proposed framework. Therefore, task reassignment in steel reinforcement, as the activity with the maximum brain load imbalance, was integrated with safety improvement strategy. Accordingly, the boundary task(s) partially assigned to helpers is “tying”, to journeymen are “installation” and “inspection”, and to foreman is “chairing”. This modification results in 78.53% improvement in brain load balance while a daily throughput of 137.1 kg/h is maintained. In the formwork erection activity, skill enhancement strategy is accommodated into revising assignment of tasks. To promote skill level of helpers and journeymen, they are involved in “marking and cutting” and “installing handrails”, respectively. Subsequently, a 39.89% reduction in brain load variance within this crew is observed. Finally, revising job assignment in concreting activity is driven by the aging problem. As a result, helpers, as the youngest subgroup, are engaged partially in “compacting” and “finishing” poured concrete. As shown in Table 4.b, this has decreased brain load imbalances from 88.65 to 39.23.

Table 4.b also highlights the partial assignment of tasks as the key to smooth transition from a traditional approach to the proposed framework. The ratio of a task newly assigned to a subgroup is shown in Figure 4. As Figure 4.a depicts, journeymen have been identified as the subgroup with the lowest brain load and hence, they assist helpers and foreman with approximately 26% of installation and 33% of inspection jobs, respectively. To minimize brain load difference for safety protection purposes, the simulation model also suggests assignment of 11% of tying and 20% of chairing to helpers and foreman, respectively. Figure
4.b shows the daily variations in the ratio of newly assigned tasks to helpers and journeymen to train them for a higher skill level. As shown, a helper is allowed to take part in up to 28% of marking and cutting and suggested contribution of a journeyman to installing handrails is between 15% and 18%. On the other hand, assignment of 21% of compaction and 9% of finishing to young helpers of concreting crew is suggested by the results of analysis to address the aging issue.

While the primary objective in the modified job assignment is to minimize brain load variance, the simulation models also show that integrating different strategic HR targets into the task planning can gradually increase the throughput of the team. As seen in Table 4.b, maintaining safety level of workers in steel reinforcement may lead to a 3.79% increase in the average production rate achievable after four days. This can be attributed to either learning opportunities in the new tasks or the boost in the learning capacity at moderated brain load, as suggested by cognitive load theory of Sweller (2012). Similarly, a better workload distribution integrated with skill enhancement and workforce rejuvenation may result in slight improvements in throughput, as reflected by 1.33% (8.38SMCA/h) and 6.46% (6.42m3/h) increase in the production of formwork and concreting, respectively after four days.

The highest improvement is achieved in concreting activity, in which the learning opportunity is the lowest (91-97%), highlighting the importance of engaging young workers. The importance of engaging young workers has been also highlighted by Ahmadian et al. (2015), where a trade-off between aging concerns and experience was shown to be crucial in crew selection. According to the multiskilling strategy employed, workers are expected to participate in all the tasks involved in steel reinforcement, formwork erection, and concreting, as shown in Table 4.C, regardless of the main skill they possess (Burleson et al., 1998). Multiskilling results in 28.3% improvement in daily throughput and a significant reduction of
77.49% in overall brain load differences, when compared to single-skilled strategy. This has been achieved through utilizing the learning opportunities in new skills that can be captured by all, and specifically by young workers.

a) Maintaining Workers’ Safety

b) Skill Enhancement

c) Addressing Aging Problem
The adjustments suggested by the model and its results have been discussed with the case project experts and the contractor’s executives. There is a consensus amongst them that improved workload balance is achievable as they expect a collaborative atmosphere can potentially resolve flaws in planning workers’ utilization in real course of project. They also anticipate the increases in throughputs offered by the model to be realized through removing idleness and grabbing motives of young workers when learning a new task. Furthermore, the contractor’s executives assess HR strategies integrated into project execution reasonable and innovative. Nevertheless, they insist implementation of the model requires intensive managerial controls as well as an incentive regime to enforce collaboration of workforce, particularly when a skilled worker is required to help with simpler tasks.

The framework developed in this study is built on a popular brain load theory. It provides a tangible and practical basis to balance workload amongst workers and the human resource strategies are integrated to the process, simultaneously. While the scales used in the present study have been adopted from a reliable source, its application to other construction operations demands a prior review and perhaps, adjustments. Moreover, effective use of the proposed framework relies on availability of detailed performance data which is tedious and costly in some operations. The proposed job assignment process takes into account the objective demands imposed by the tasks along, as well as some of the subjective aspects of workload, mainly with regard to skills and experience of workforce. This proposed framework, however, doesn’t consider other factors that may contribute to the workload such as out-of-workplace conditions, psychological and physiological differences of workforce, and their ethnic background. Future research is needed to improve the work by seeking ways to accommodate such factors in the analysis. Finally, practical implementation of this
approach may require obtaining permissions from relevant authorities particularly in terms of labour rights and safe work practices.

5. Conclusions

A novel framework for crew level planning was proposed to systematically minimize workload imbalances within a crew through accounting for brain resource demands of the jobs. The proposed framework also integrates HR strategies with the job assignments process as a cost-effective on-the-job training approach with tangible outcomes. Analysis of tasks are performed based on their demand for visual, auditory, cognitive, and psychomotor types of brain resources and task assignments are governed by an HR strategy to maintain safety, enhance workers’ skill level, address the aging problem, or implement multiskilling.

Application of the proposed framework to a concreting case project was shown using a DES simulation environment in which scenario based optimization of job assignments can be experimented. The results show that the new approach in crew level planning not only achieves its primary objective in reaching an even workload distribution, but also leads, in some cases, to improved throughput. The latter is achieved in cases where workers are allowed some time to learn new tasks while their moderated brain load enhances the effect of learning. The value of trusting young and inexperienced workforce is highlighted particularly in implementation of “aging problem alteration” and “multiskilling” strategies in which young workers are central to the strategy, as shown by the highest improvements recorded. The results of this study indicate that partial assignment of tasks can be deployed to ensure smooth transition from traditional job assignment to the proposed framework. The results also indicated that the proposed framework also may benefit HR development in a cost-effective manner with tangible outcomes, as demonstrated by possibility of on-the-job execution of HR strategies.
While accounting for the objective demands imposed by tasks and a number of subjective aspects of workload, such as skill and experience, the proposed framework can be improved by considering other human-related factors that can strengthen its subjective side, including out-of-workplace conditions, psychological and physiological differences of workforce. Future research is required to seek ways to accommodate these factors into the framework in order to improve accuracy of the results.

6. References


CONSTRUCTION INDUSTRY INSTITUTE (CII) 2013. Advanced work packaging: Design through workface execution. Implementation resource 272-2. Austin, TX: Univ. of Texas at Austin.

CONSTRUCTION OWNERS ASSOCIATION OF ALBERTA (COAA) 2014. COAA workface planning rules. Edmonton, AB, Canada.


MILLER, G. A. 1956. The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, 63, 81-97.


NOAKES, T. D. 2012. Fatigue is a brain-derived emotion that regulates the exercise behavior to ensure the protection of whole body homeostasis. *Frontiers in Physiology*, 3.


SAFEWORKAUSTRALIA 2013. GUIDE FOR MANAGING THE RISK OF FATIGUE AT WORK. Safe Work Australia.


