Dynamic Scheduling Framework to Overcome Deficiency of Skilled Workers

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Abstract –

Substantial investments in infrastructure world over and rapid advancement in construction technology has created acute shortage of skilled workers. The skill deficiency gets aggravated further due to absenteeism, migration, etc. In practice, it was observed that there exist several partially trained semi-skilled workers having expertise in one or more trade. Using these semi-skilled workers as substitute can address the shortage of skilled workers to some extent. On the contrary, skilled workers alone are considered while planning and scheduling in most of the construction projects. Here, the potential capability of these partially trained workers remains unexploited because of their default grouping with unskilled workers.

The root cause of this skill treatment can be the absence of standardised system of screening and classification of workers into different skill category as highly skilled, skilled, semi-skilled, or unskilled and the ambiguity in updating or maintaining the worker's database. Hence, the objective of the present study is to review the "skill" levels and the worker's skill utilization to the maximum extent possible. To achieve this, a framework has been proposed to generate worker's multi skill database (WMSD) and dynamic scheduling to address the uncertainty caused by deficit of skilledworkers.

Keywords –

Dynamic Scheduling Frame Work, Workers Multi Skilled Database (WMSD), Productivity Matrix, Absenteeism

1 Introduction

Construction industry remains one of the most labour intensive industries despite mechanization. This implies although mechanisation reduces the overall requirement of workers in a project, yet demand of skilled workers has been increasing with regard to emerging tools, techniques, new construction material, and technology [1].

Quality construction typically demands a certain number of skilled workers in a crew [2]. The formation of skilled workers crew becomes restricted due to fragmented construction industry, system of subcontracting and short employment duration. Also, few workers acquire proficiency in more than one trade/craft (i.e., multi-skilled) due to frequent changes in work assignment [3, 4]

As each construction project is unique and requires minimum number of skilled workers to meet quality and contract conditions, only skilled workers are generally considered while scheduling and the partially trained workers (i.e semi-skilled or multi-skilled workers) are ignored due to their default clubbing with the unskilled workers. Low wages, poor working condition and overall poor image of the construction industry forces the workers to frequently absent, migrate to other countries, etc. [5]. This short term deficiency of skilled workers reduces crew productivity at activity level and the impact of the same gets magnified at project level resulting into time-cost overrun.

The present situation offers an opportunity to utilise the partially skilled workers efficiently to overcome short-term scarcity of skilled workers. This can be achieved by developing an appropriate dynamic scheduling framework that is reliable. In the long term, the offer of longer employment, higher compensation and variety in assignment to semi-skilled and multi-skilled workers are likely to motivate huge pool of unskilled workers towards early skill upgradation and thereby reduce absenteeism.

Hence, the objective of this study is to propose a framework which utilises semi-skilled and multi-skilled workers as substitute to limit crew productivity loss caused by absence of skilled workers.

2 Background

2.1 Defining Skill

Defining skill itself is complex, highly subjective, and means differently to different researchers. Workers perceive skills as competence acquired through education, training and experience which may not have been put to use in the past (i.e effective skill), the employer considers only a portion of the effective skill suitable for impending task (nominal skill) and sociologist considers that skill is an evolving processes emerging from social interaction between workers and employer [6]. Generally skill is considered as "a set of knowledge, attributes and capacities that enable individual workers to successfully and consistently perform an activity or task and that skill can be built upon and extended through training, learning and experience" [7]. Irrespective of industry, International Standard Classification of Occupations (ISCO-08) divides workers into four skill levels based on education and job specific training and experience (i.e., 1st level-primary education, 2nd level-high school, 3rd level-graduation and 4th level- post graduation) [8]. The groups relevant to construction industry are 1) construction professional (i.e., engineers, project managers and technical associates) to have graduation and post-graduation and training; 2) skilled construction workers, plant/ machine operators, assemblers require high school education, craft certification like ITI/Diploma and experience of 2 years or more; and 3) Other construction workers or unskilled workers.

2.2 Construction Workers at Site

CII in 1998 proposed multiskilling as "worker utilization strategy where workers in possession of a range of skills appropriate for more than one work process and these can be used flexibly on a project or within an organization, not limited to traditional job boundaries", to reduce overall number of skilled workers[9]. However, it may be difficult for a worker to acquire 'skilled' status in more than one trade due to evolving work processes.

In India, there exist three distinct career paths for construction worker as 1) traditional craftsmen (who consider the work as family tradition and learn trade expertise from their parents); 2) higher secondary qualified student (who joins ITI or other structured skill development program to get trained in the trade of their interest); and 3) migrant workers (who move as nomads for livelihood) [10]. The traditional construction workers are small in number and focused on specialist work like repairs and maintenance of heritage structures, monumental stone work and carvings etc. The ITI qualified workers form the major chunk of skilled construction workers; whereas, third category comprises all other construction workers with many of them partially skilled but clubbed with unskilled workers while project scheduling [11]. These partially skilled workers may not be able to execute quality work in isolation; but will have decent productivity when employed under supervision of skilled worker in a crew [12].

2.3 Scheduling Techniques

2.3.1 MRCPSP (Multi-Mode Resource Constrained Project Scheduling Problem)

RCPSP [13] assumes that an activity can be executed only in one mode (i.e. specific type of resource required for fixed duration to execute an activity), contrary to the fact that most of the activities can be executed in more than one mode. Here, the schedule which considers all possible modes offers more efficient utilization of the resource and is referred as MRCPSP. Invariably researchers make four basic assumptions - any worker can do any job; mode of execution cannot be changed during execution; availability of manpower is uniform; no breaks allowed once an activity is started [14]. However, these assumption makes such schedules unrealistic.

2.3.2 MSPSP (Multi-Skilled Project Scheduling Problem)

Kadrou (2006) highlighted the complexities and issues associated with modelling of multi skilled (MS) worker with varying degree of productivity and did not test the proposed solution with Project data [15]. There will be additional modes if MS worker capable to perform more than one job are considered making scheduling process complex. However, employment of MS workers brings in additional flexibility, encourages innovation [16], saving of 5-20% labour cost, about 35% reduction in required workforce [17]. However benefits are marginal beyond 20% MS workforce, and little benefits beyond 2-3 trades [18].

Most of the MSPSP studies focused on optimum utilization of skilled workers possessing equal expertise in more than one trade which is an unrealistic assumption. Hegazy et al [12] suggested storing individual workers multi skill data (i.e semi-skilled workers with expertise in more than one trade) and substitution (i.e 2 semi-skilled workers for each skilled worker) to overcome skill deficiency. But, several issues were left for further research (i.e method to identify multi skilled workers in project site, substitution rules assuming non uniform skill level and productivity, possible deviations in quality of work by substituted workers, constant resource pools over the activity duration, decision process of selecting important activities to which resources are to be diverted). Implications of short term skill deficiency while scheduling have not been attempted in these studies although a common phenomenon in view of high demand, poor working conditions and wide spread absenteeism exist.

In view of above there is a need to define skill level amongst construction workers and formulate a suitable frame work which allows substitution of partially trained workers to overcome short term deficiency of skilled workers and provide realistic project duration considering variation in crew productivity due to substitution, if any.

3 Skill levels in Construction Workers

In the present study five category of construction workers have been considered as described below;

1. Highly Skilled (HS) – Worker can visualize the entire scope of work, impart training to crew, ability to coordinate work of other crews/craft and ultimately can produce the best quality work.
2. Skilled (SK) - Can read engineering drawing, lead the crew to execute all kind of works and overall an ideal quality/ productivity levels.
3. Semi-Skilled (SS) - Will have expertise in any one work process and can work as team member in a crew and on the whole expected to have desirable productivity levels
4. Multi Skilled (MS) – Semi skilled worker who have capabilities in more than one work processes/trade.
5. Unskilled (US) - Untrained form of worker who can be used as helper in any crew.

4 Dynamic Scheduling Frame Work

4.1 Assumptions

The present study uses simplified yet realistic assumptions reflecting actual site conditions and are listed below;

1. A project can be divided into fixed number of activities with predefined logic constraints.
2. The skill screening process is expected to be done fairly by site in-charge/ experts as per project requirement.
3. A crew can be worked out for each activity using work study giving output equal to baseline productivity (BP) at economical cost.
4. Due to higher demand of SK and HS in any trade and presence of very few SK and HS in more than one trade, secondary and tertiary trade for SK and HS were neither captured during screening nor considered while scheduling.
5. A productivity table can be generated indicating productivity of various feasible combination of crew using work study. The productivity table can be further extended to reflect fixed number of likely working conditions.
6. Once known in the beginning, desired number of skilled, semiskilled and multi-skilled workers can be arranged on desired date with minimum fluctuation.
7. Workers availability for any date can be simulated to represent the real presence of workers during project execution.

4.2 The Framework

The initial schedule generated based on network scheduling technique can be improved in successive stages to; 1) reduce project duration by reducing duration of critical activity and efficient utilisation of critical plant/ machineries/ workers; 2) reduce cost of hiring/ firing of workers and mobilisation/ demonization cost of plants/ machineries by resource levelling; 3) Limit time-cost overrun by identifying minimum requirement of workers including reserve workers to counter absenteeism and factoring loss in crew productivity despite substitution; 4) Realistic schedule utilising actual availability of workers from dynamically updated skill database. The proposed dynamic scheduling framework is represented as a schematic diagram in figure 1.

4.3 Worker's Skill Database

The skill level of an individual worker can at best be quantified based on nominal screening process which involves;1) Possession of ITI diploma or equivalent certification; 2) Performance on test sample task; and 3) unstructured interview formulated by site engineer and foreman. Workers are designated as 'skilled' if they possess requisite educational qualification, job specific training/experience and exhibit productivity equal to benchmark productivity. Currently, partial skills possessed by the workers are completely neglected at the time of screening.

It was observed during data collection that even this nominal practice of skill screening was seldom followed due to adhoc recruitment, work pressure and lack of concern at higher management level, and so on. And no structured worker's skill data base was available except the workers certificate. The survey also revealed that existence of several multi-skilled workers.

Therefore to generate reliable database all workers joining the project are to be tested on their primary, secondary and tertiary test because there is limited benefit of multi-skilling beyond three work processes [18]) The flow diagram shown in figure 2 shows how the workers can be categorized into HS, SK, SS, MS and US and details collected in the database.

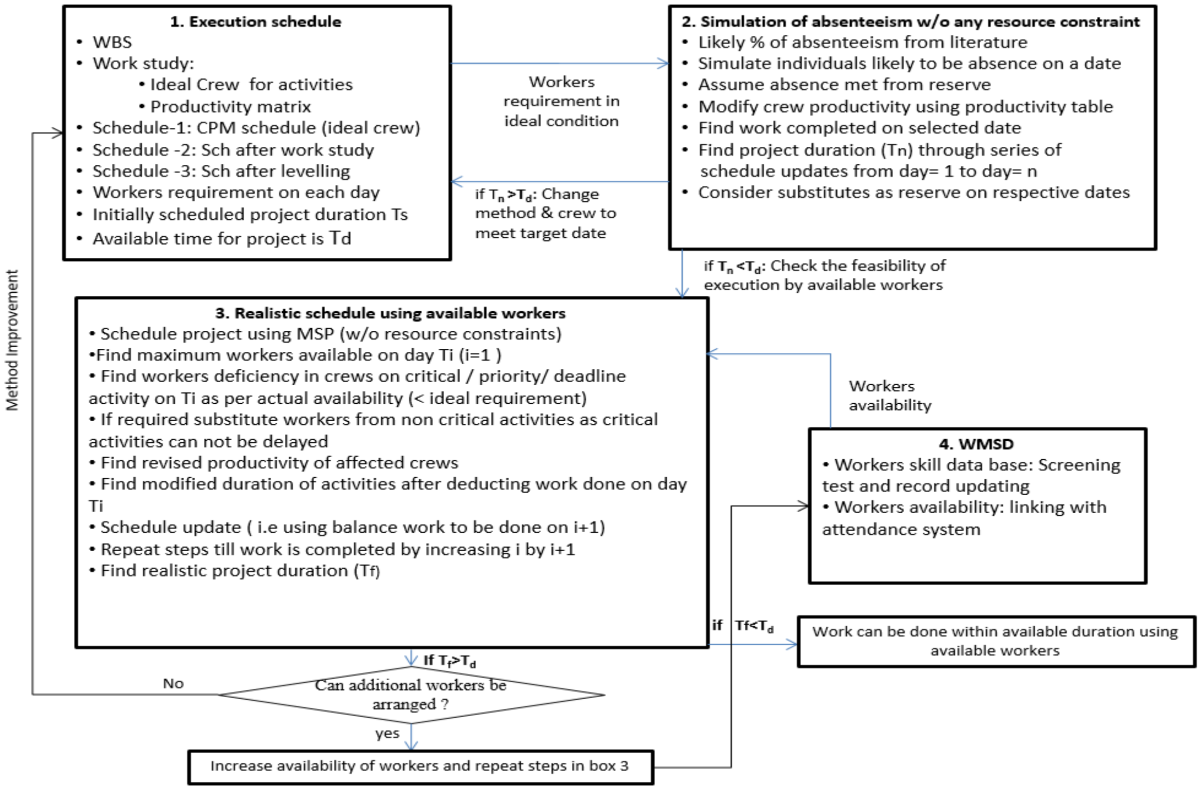

Figure 1. Dynamic Scheduling Frame Work

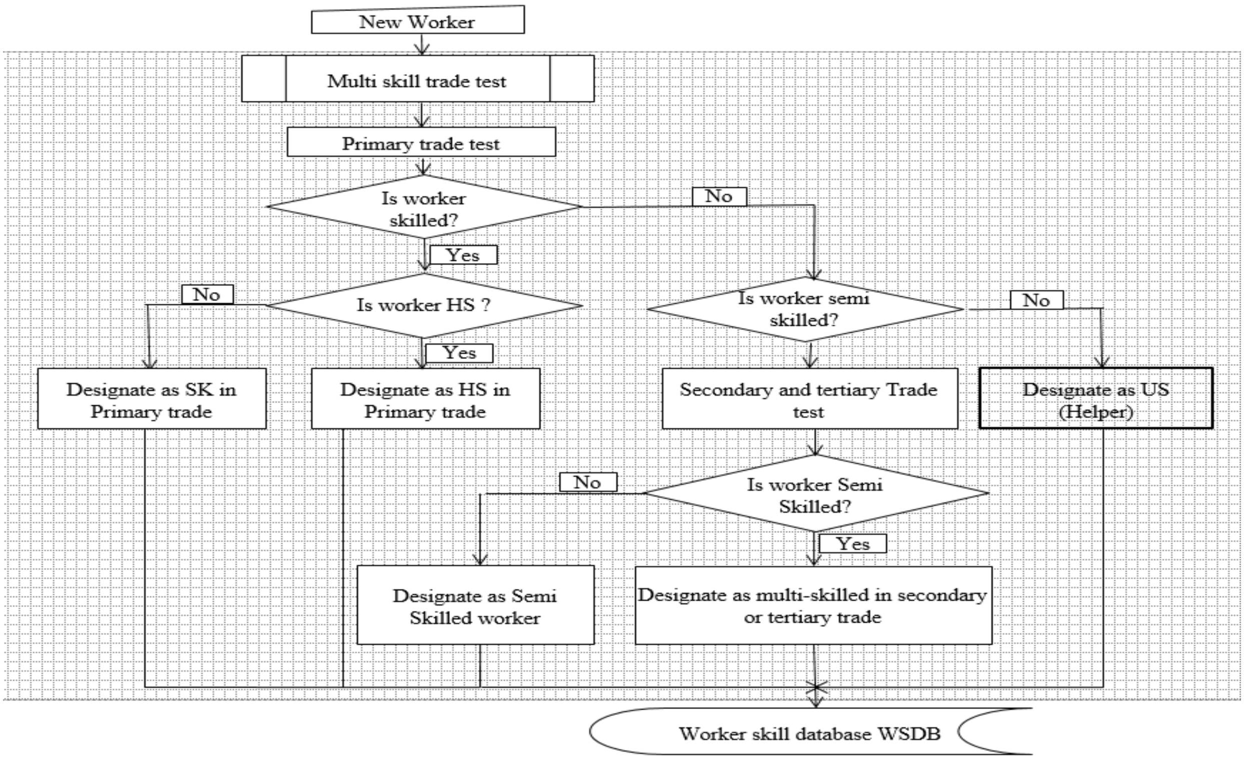

Figure 2. Flow Chart for Screening and Categorisation of Worker

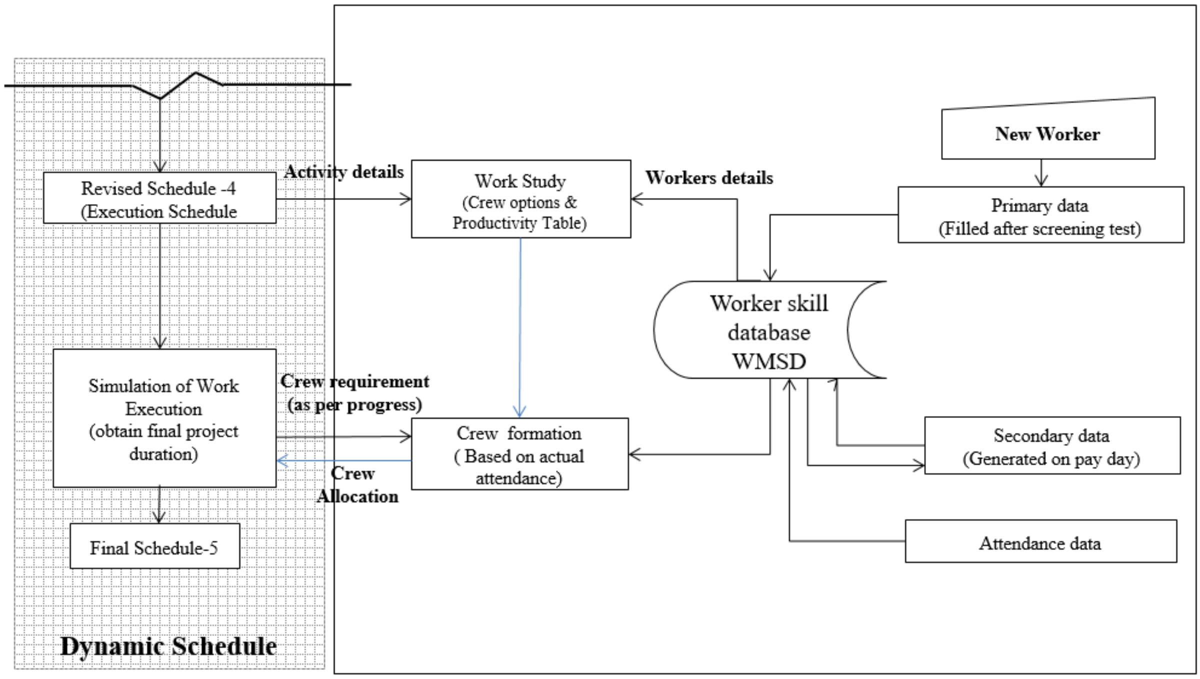

Figure 3. Flowchart for WMSD

This database can be linked to attendance module to obtain real time availability of workers and their respective skill levels as seen in Figure 3. This database can be also further extended to multi-project environment by linking the workers profile with their social identification number and managed through a third party as seen in figure 3.

4.3.1 Crew Productivity Matrix

The actual productivity of a crew for specific activity can be measured using work study [19]. The absence of a member will have adverse effect on crew productivity because rate of activity execution is a function of task complexity, desired quality in task, and skill level of workers, etc. Although it may be feasible for the crew to progress the work with less number of workers, the productivity will be lower even if deficiency is compensated by substitution due to lack of co-ordination between existing member and new member. The loss in productivity will also depend on skill of the absent worker and skill level of substitute worker [12]. In addition there may be limiting condition such as minimum number of SK workers or maximum acceptable crew productivity loss without critically affecting quality, etc. [2]. To cater all these conditions, a productivity matrix can be generated for each activity using work study.

A hypothetical productivity matrix has been shown in Table 1 to explain the concept. The matrix has three parts – 1, 2 & 3. The combination of these parts can be used to revise crew productivity. The process has been explained for an activity which ideally requires 3x SK, 6 x SS/MS, 6xUS as given in Table 1.

Example: 2 x SK workers are absent.

Considering substitution rule (Part 1 of Table 1) work can be executed even if two skilled workers are absent because 1x SK worker from original crew is still available and maximum productivity loss is only 20%. Following substitution options are feasible when 2 xSK workers are absent.

1. Case 1: If no substitution, crew productivity loss will be 20% (see Part 2 of Table 1).
2. Case 2: If 2xSK workers are substituted from reserve pool - productivity gain will be 10% and crew productivity loss will reduce to 10% (i.e 20%-10%).
3. Case 3- If void is filled by SS/MS workers from reserve pool of workers, the productivity loss will be;

- 10% (i.e 20% - 4x2.5%) if 4 Nos of SS/MS are used as substitute;
- 12.5% (i.e 20% - 3x2.5%) if 3 Nos of SS/MS are used as substitute;
- 15% (i.e 20% - 2x2.5%) if 2 Nos of SS/MS are used as substitute;
- 17.5% (i.e 20% - 1x2.5%) if 1 Nos of SS/MS are used as substitute

4.3.2 Execution Schedule

As shown in Box 1 of figure 1, process includes finding scope of work for each activity utilising work breakdown structure (WBS), ideal crew composition for these activities utilising work study and subsequent series of schedules to find execution schedule. The initial schedule will provide project duration (T_s) and workers requirement considering nil workers deficiency.

4.3.3 Simulation of Project Execution

As shown in Box 2 of figure 1, the exported report has three Excel worksheets, namely Task Table (includes activity details), Resource Table (includes resource details) and Assignment Table (includes details on resource allocation to activities). From Assignment Table trade wise resource requirement for all activities can be summed up day wise.

Table 1: Productivity Matrix

Part 1: Substitution Rules						
1. Minimum 1 SK to be present in a crew 2. Crew not employed if Productivity loss > 33%						
Part 2: Productivity loss due to absence in %						
Worker	Ideal Nos	Min	Absence			
			-1	-2	-3	-4
SK	3	1	-10	-20	NA	NA
SS/MS	6	3	-5	-10	-15	NA
US	6	5	-5	NA	NA	NA
Part 3: Productivity gain due to substitution						
Worker	Ideal Nos	Max Subtn	Substitution			
			1	2	3	4
SK	3	1	5	NA	NA	NA
SS/MS	6	4	2.5	5	7.5	10
US	6	4	1.25	2.5	3.75	5
Note: The productivity loss and gain to be found after work study.						

For given % of absenteeism, likely absence of specific workers can be simulated. Assuming availability of adequate reserve, modified productivity of affected crew using productivity matrix (Table 1) and revised project duration can be calculated. There are two possible outcomes after considering productivity loss due to absenteeism;

1. Likely project duration considering absenteeism is more than available time ($T_n > T_d$). In this case duration of activities on critical path would require reduction through method study and identification of ideal crew combination (see arrow from box 2 to box 1). The revised crew composition may not give best individual worker productivity but revision will be unavoidable to meet project dead line (T_d). The simulation will have to be attempted again till likely project duration (T_n) is less than time available (T_d).
2. Likely duration is less than available duration ($T_n < T_d$). In this situation, attempt can be made to find project duration based on available workers (see arrow from box 4 to box 3, figure 1). There could be two possibilities;

- Calculated project duration is more than available time ($T_f > T_d$);
  - In case additional workers can be arranged, steps given in box 3 to be repeated.
  - If additional workers are not available, schedule can be improved through method improvement and flow process design (Box 1, figure 1).
  - In case it is not possible to meet the project deadline despite method revision, the project delay would have to be accepted.
  - If calculated duration $T_f < T_d$, the schedule can be used for execution of workers utilising available workers.

5 Methodology

5.1 Execution schedule

Scheduling based on logic constraints is simple and adequate for monitoring by executives at project level. However, project manager has to face daily challenge of managing crucial resource. Thus resource constrained project scheduling (RCPSP) become a necessity. RCPSP requires crew composition for each activity and corresponding activity duration. Activity duration and ideal crew composition can be obtained using WBS and work study. In traditional RCPSP problems, the resource allocated for any activity is assumed to be uninterrupted during the execution and activity execution is considered by a unique crew taking fixed duration. In case of MRCPS multiple modes are considered for execution of activities. This makes scheduling very complex without any surety that mode selected through MRCPSP will be available during execution.

To overcome the challenge two pronged strategy needs to be adopted;

- Find all possible crew combination for execution of each activities and likely rate of execution in the form of productivity matrix (Table 1) using work study.

- Identify important activities {i.e activities on the critical path, activities having completion deadlines, and activities having high priority (not on critical path but engaging high rental equipment)} and allocate resources on priority before attempting other activities

The proposed steps to find execution schedule are as follows (Box 1 of figure 1);

- Identify ideal crew composition for work packages or activities identified from WBS.
- Schedule the project assuming that desired crews can be arranged whenever required using MSP (Micro Soft Project software).
- Find scheduled project duration t_s, required number of ideal crews, crew employment period and requirement of workers on each day.
- Compare desired duration (t_d) with scheduled project duration (t_s).
  - If $t_s > t_d$: It infers that despite abundance of workers, it is not possible to execute the work in time. Hence, need to improve technology to change the logic constraint and/or improve the crew productivity (i.e method change) to shorten the critical path.
  - If $t_s < t_d$: It infers that execution is feasible within available duration when workers are in abundance but may not be feasible under resource constrain and productivity loss due to absenteeism etc. Hence there is need for simulation of productivity loss due to short term deficiency and finding requirement of reserve pool of workers to limit time cost overrun.

5.2 Simulation of Project Execution

The schedule can be further improved by simulating workers absenteeism to find reserve pool of workers and subsequent simulation utilising available workers less reserve to cater likely absenteeism etc. The information about availability of workers can be obtained from dynamically updated WMSD. The steps are as follows;

- On a selected date, workers likely to be absent can be identified using simulation for given % of absenteeism or industry average of absenteeism over duration t_d.
- On day one (t=1) identify activities in progress and affected by absent individuals. Modify their productivity on t=1 assuming that absence met from reserve pool of workers (see section 5.2.2). Critical and important activities to be given priority.
- Calculate quantum of work executed by modified crew in affected activities on t=1 and calculate additional time required to complete those activities assuming no absence afterwards.
- Modify activity duration of all affected activities at the end of day t=1 by finding % of work balance after t=1 and find duration of remaining part of the activities, assuming that all workers are present thereafter.
- On t=2, use modified activity duration to reschedule project using any network scheduling software (i.e MSP etc).
- Through series of schedule updates, find project duration (T_n) when no balance work is left. This will be project duration with abundance of workers and productivity loss due to absenteeism.
- If $T_n > T_d$: It infers that absenteeism will delay the project despite availability of ideal crew & requisite reserves. Hence, there will be a need to improve technology to change the logic constraint and/or improve the crew productivity (i.e method change) to shorten the critical path.
- If $T_n < T_d$: It infers that work can be completed with ideal crew combination and in presence adequate reserve.
  - Available total buffer is equal to T_d-T_n days.
  - As per the steps given in Box 3, project duration can be found considering available worker from WMSD less required reserve.
  - Find realistic project duration (T_f).
  - If $T_f > T_d$
    - Arrange additional resources and follow steps given in Box 3, or
    - Change activity duration through method improvement and repeat steps given in Box 1, 2 and 3 of figure 1 in a sequence.

6 Discussion

Categorisation of workers based on their education, proficiency in work process, experience and existing norms in Indian proposed (see section 3) will yield desired result when the WMSD is built over a period of time. The initial category will evolve with progress of time when workers employment duration, productivity and sincerity (i.e., less absence, less sick leaves, etc.) are mapped (see section 4.3). The productivity matrix proposed in section 5 will require rigorous investigation using work study tools and form the first set of standardisation, presently lacking in construction industry. The recognition of crew productivity loss due to sudden change in crew composition will motivate various stake holders in evolving suitable approach to limit the short term absence. Concept of creating reserve pool of workers by simulating absenteeism will guide contractors regarding number of workers to be kept in their permanent roster. This reserve can be utilised by main contractor to assist subcontractors when they face short term deficiency. The realistic schedule will result in lesser variation in activity durations and higher productivity as well as limited time-cost overrun. Once automated, the final schedule will facilitate project managers to select best possible crew composition for activity in progress on selected date considering the work progress up to previous day. The awareness about likely completion date on any day will facilitate all stakeholders to take appropriate measures.

7 Limitations

The proposed framework is being applied on actual project data to validate concept and hence minor changes in the framework cannot be ruled out. The concept focused on short term deficiency of skilled worker only. In addition, assumption given in section 4.1 may itself become the first set of challenge. Since, entire process is complex, the automation with different modules catering different types of project will be essential in creating of robust WMSD. Although it may be easy to create database for workers engaged in one project yet database involving input from multiple subcontractors located in different geographical locations would be a challenge but essential to get real benefit.

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