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Integration of Linear Scheduling Method and the Critical Chain Project Management

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Abstract: Integration of repetitive and non-repetitive scheduling methods utilizes the merits and unique features of those methods. This paper presents a new scheduling method for repetitive projects that integrates linear scheduling (LSM) and critical chain project management (CCPM) methods. The proposed method introduces a framework for scheduling of repetitive projects; accounting for constraints of resources continuity and uncertainties associated with activity durations. It introduces a new buffer, named resource conflict buffer (RCB) to account for delays that may occur due to conflict in controlling resources among successor and predecessor activities. The developed method provides a systematic procedure for identifying several critical chains to replace the visual identification method that is currently used in linear scheduling. The features of the proposed method are illustrated in a case example for scheduling of repetitive projects using an integration of LSM and CCPM scheduling techniques. A discussion of results is performed and conclusions are drawn to highlight the features and capabilities of proposed method.

Keywords: Linear Scheduling Method; Critical Chain Project Management; repetitive scheduling.

1 Introduction

Scheduling of construction projects can be categorized into repetitive and non-repetitive. Repetitive scheduling contains cycles of repetitive activities such as those encountered in housing units, highways, pipelines, and railways. Non-repetitive scheduling (network scheduling) fits construction projects that do not require continuity of resources. These two types of scheduling are also referred to as activity-based network scheduling and location-based management scheduling (LBMS) (Kenley and Seppänen 2010). Unlike network-based scheduling, LBMS is geared to maintain continuity of resources.

Planning and scheduling of construction projects should consider variability and uncertainty to account for the dynamic nature of construction (Bakry 2014). Limited number of methods incorporated uncertainty for repetitive scheduling (Bakry 2013). Simulation is utilized to account for uncertainty in most of these methods while few others use buffers in linear schedules (Bakry 2013 and Slorup 2014). However, simulation models cannot maintain on its own the continuity of resources for repetitive scheduling. An external algorithm has to accompany simulation models to cover this shortage (Yang 2002). Existing linear scheduling methods that utilize buffers either did not consider the acceleration for repetitive schedules, provide formulated procedures, or use visual method for critical sequence identification. Unlike existing scheduling methods, the proposed scheduling method integrates CCPM with LSM in a systematic procedure that; formulates the scheduling process while maintaining continuity of resources, allocates buffers while considering the required confidence level, identifies all critical chains in the schedule and provides aggressive schedules that allow, where applicable, for acceleration of repetitive construction activities.

2 Literature review

Existing scheduling methods that integrate repetitive and non-repetitive scheduling are grouped into two categories; deterministic and stochastic. Each category includes scheduling methods with and without optimization. The capabilities and limitation of these methods are summarized in Table 1. Those without optimization do not make efficient utilization of resources in achieving project targeted objectives, whether deterministic (Laramée 1983; Russell and Wong 1993; Suhail and Neale 1994; Ammar 2013) or stochastic (Schoderbek and Digman 1967; Kankainen and Seppänen 2003; Seppänen 2009; Slorup 2014; Salama et al. 2016).

Methods which consider optimization either focus on minimizing project duration (Selinger 1980, Russell and Caselton 1988), and/or cost (Moselhi and El-Rayes 1993; El-Rayes and Moselhi 1998; Hassanein 2002; Hassanein and Moselhi 2004; Ranjbaran 2007). Dynamic programming was utilized in optimization of this class of projects without interruptions as in Selinger (1980), or with pre-determined work interruptions as in Russell and Caselton (1988) to reduce project duration without considering the impact of project cost. El-Rayes (1998) introduced an algorithm to account for cost in the optimization and modeled interruptions based on a set of heuristic rules. Others in this group were domain specific. For example, Hassanein and Moselhi (2002 and 2004) optimized schedules of highway construction considering combined impacts of project cost and duration. Ranjbaran (2007) extended the work of El-Rayes (1998) by presenting an object oriented model for planning, scheduling, and control of high rise building without optimizing resource sharing between multiple projects. However, these methods collectively neither consider uncertainty nor provide tracking and control capabilities

The second category of methods integrate repetitive and non-repetitive scheduling while considering uncertainty associated with durations of activities. Those which utilized optimization

vary in their capabilities to identify critical path, provide visualization, and/or making use of critical chain management. Seppänen (2009) developed VICO as a location-based software that utilizes 3D, 4D and 5D building information modelling (BIM). VICO does not have a structured method for buffer sizing. It assigns buffers subjectively; larger if the predecessor activity has high variability, when activities has little or no total float, or when activities are planned to be performed continuously.

Slorup (2014) applied the buffering techniques of critical chain project management (CCPM) in location based management scheduling (LBMS). However, Slorup (2014) did not present a formulation for this method or a procedure for identifying critical sequence in respect to constraining resources. Salama et al. (2016) suggested (BIM) based integrated framework for planning and scheduling of hybrid offsite construction projects using LSM and CCPM. However, this framework utilizes a visual method only for identifying critical chain.

Bakry et al. (2013) presented a method that consider schedule optimization to minimize project duration or cost. This method produces a basic (LSM) schedule with deterministic activity durations, and a buffer component that utilizes fuzzy sizing and insertion of buffers to account for uncertainty. However, it is a single objective optimization method that addresses either duration or cost, but not both.

Ghaffari and Emsley (2015) reviewed 120 studies related to CCPM and presented a comprehensive overview highlighting the current status and future potential of CCPM research. The application of LBMS in CCPM was cited in 21 futuristic research areas. Both LBMS and CCPM utilize buffers to protect schedules in construction projects. However, unlike LBMS based methods the network based CCPM methods do not consider the continuity of resources. In summary, the above methods individually and /or collectively were either incapable of

accounting for uncertainty or for estimating reliable buffers. The developed method considers the uncertainty while utilizing linear scheduling for repetitive projects. The method is generic and resource driven that integrates (LSM) and (CCPM).

3 Method

The proposed method integrates CCPM and LSM; the aggressiveness of CCPM leads to shorter schedules while LSM visualizes repetitive processes and accounts for continuity of resources. The framework of proposed method is illustrated in Figure (1).

3.1 Calculation of aggressive and safe activity durations:

Safe activity duration is defined as duration estimate that includes enough safety to protect activities execution against contingencies. Aggressive activity duration is the average estimate without safety time (Dilmaghani 2008). Activity aggressive duration depends on the calculation of aggressive productivity rate and the constrained productivity rate (CPR) at 50% confidence level of resources availability as presented in Equation (1). Activity safe duration depends on the calculation of constrained activity productivity rate (CPR) at 90% confidence level of resources availability as presented in Equation (2).

Calculation of aggressive and safe durations using CPR leads to identification of the controlling resource for each activity as presented in Equation (3). The controlling resource is defined as the resource that controls the activity duration.

$$D_{i,j} (AG) = \text{activity quantity} / \text{CPR}_{i,j} (AG) \quad (1)$$

$$D_{i,j} (CL) = \text{activity quantity} / \text{CPR}_{i,j} (CL) \quad (2)$$

$$\text{CPR}(CL) = \text{Activity total quantity (any unit)} \times \frac{\text{available resources output/day}(CL)}{\text{Total activity required resources output}} \quad (3)$$

Where,

$D_{i,j}$ (CL), represents the safe duration of activity “i” in process “j” with given confidence level “CL”.

$D_{i,j}$ (AG), represents the aggressive duration of activity “i” in process “j”.

CPR_i (CL), represents constrained productivity rate of activity “i” with resources availability at “CL” confidence level.

CPR_i (AG) represents constrained productivity rate of activity “i” with resources availability at 50% confidence level.

3.2 Sequencing activities based on aggressive durations (average schedule):

The aggressive schedule is sequenced using Equations 4 and 5 based on aggressive durations by deducting all safety durations from activities as per the CCPM rule of aggressiveness. Goldratt (1997) attributed unsatisfactory performance of schedules to two human behaviors, known as Parkinson law and student’s syndrome. Parkinson law implies that if execution crews complete activities in less duration than scheduled, early completion of activities will not be reported. Student’s syndrome implies that if activities are assigned longer duration than it requires, then execution crews work at a relaxed rate. Hence, schedulers avoid Parkinson law and student’s syndrome by deducting safety durations and if any activity is delayed then feeding and project buffers absorbs this delay.

$$SD_{ij}(AG) = \text{Max} [FD_{ij-1} (AG), FD_{i-1,j}(AG)] \tag{4}$$

$$FD_{ij}(AG) = SD_{ij} (AG)+ D_{ij} (AG) \tag{5}$$

3.3 Maintaining the continuity of aggressive schedule:

LSM rules are applied to maintain the continuity of resources for all activities. Figure (2) illustrates the developed procedure for maintaining the continuity of resources. Russell and

Wong (1993) defined work continuity as postponement for start date/time (SD) of activities until continuous work is guaranteed. This rule is applied in the proposed procedure to maintain the continuity of work for all activities “i” in the same process “j” as well as the continuity of work among consecutive processes using Equations (4) and (5). Equation (4) calculates the SD of an activity “i” as the maximum between the finish date (FD) of same activity “i” in preceding process “j-1” and the FD of its preceding activity “i-1” in the same process “j” to maintain continuity in the same process as well in the consecutive processes. Equation (5) calculates the FD of activity “i” in process “j” as the sum of SD_{ij} calculated using Equation (4) and the duration of activity “i” in process “j” calculated using Equation (1) and (2). As long as “j” remains smaller than the total number of processes (m), this procedure is repeated for all activities “i” in all processes “j” to maintain the continuity of processes in the developed linear schedule.

3.4 Resolving resources conflicts:

Resources conflicts is an important issue in CCPM scheduling because solving these conflicts changes the traditional critical path into the critical supply chain which is constrained by resource limitations as shown in Figures (3) to (5). The critical path in Figure (3) including activities A, B, C, F, I, and K changed into the critical chain including activities A, B, D, F, I, and K. Three feeding buffers (FBs) were assigned after non-critical chains which are emerging into the critical chain to absorb delay in non-critical chains without delaying the project. Project buffer (PB) is added at the end of critical sequence that has the maximum buffer to absorb the possible delays of its activities.

However, the continuity constraint in linear scheduling should be respected. If two or more sequential activities share the same controlling resource, then the priority is given to predecessor

activities to respect the continuity constraint of aggressive schedule. Hence, the successor activities start only if there are enough resources to ensure its continuity while logic relationships between preceding and succeeding activities are respected.

However, if the normal productivity rate of preceding activity is equal to or larger than the constrained productivity rate of the aggressive activity (CPR_{AG}) then there are no residual resources quantities that could be shared with the succeeding activity. In this case, starting the first activity of succeeding process is related to the end of preceding process last activity as presented in Equation (6). However, if the normal productivity rate of preceding activity (without resources constraints) is lower than aggressive constrained productivity rate (CPR_{AG}) then, enough resources are available to start the succeeding activity before completion of preceding activity. The overlap between the two activities is calculated using Equations (7) and (8).

$$SD_{i,j+1(AG)} = FD_{i+n,j(AG)} \tag{6}$$

$$Q_R = Q_T - Q_C \tag{7}$$

$$O_{RC} = QR / \min (CPR_{AG}, PR_{AG}) \text{ for succeeding activity.} \tag{8}$$

Where,

Q_R : Residual quantities in preceding activity.

Q_T : Total available quantities according to constrained activity productivity rate in preceding activity.

Q_C : Resources quantities consumption during normal duration in preceding activity.

O_{RC} : Overlap due to resources conflicts.

The variability of resource for preceding activity shifts the start of the succeeding activity by creating another overlap (O_{VAR}) between the preceding and succeeding activities. The difference

between O_{RC} and O_{VAR} creates a resources conflict buffer (RCB) as illustrated in Equations (9) to (11). RCB accounts for conflict in availability of resources for preceding and succeeding activities as shown in Figure (6).

$$O_{VAR} = (Q_{50\%} - Q_{90\%}) / \min(CPR_{AG}, PR_{AG}) \text{ for succeeding activity.} \quad (9)$$

$$RCB = O_{RC} - O_{VAR} \quad (10)$$

$$SD_{i,j+1}(AG) = FD_{i+n,j}(AG) + RCB - O_{RC} \quad (11)$$

Where,

O_{VAR} : Overlap of resources quantities variability for preceding activity.

$Q_{50\%}$: quantities in preceding activity with 50 % confidence in availability.

$Q_{90\%}$: quantities in preceding activity with 90 % confidence in availability.

RCB: Resources Conflict buffer.

3.5 Identification of critical sequence:

Finding the critical sequence is crucial for integrating CCPM and LSM because CCPM is based on identifying the critical path constrained by resources limitation, while the resources continuity should be maintained according to LSM. The critical sequences for the aggressive schedule are identified using the newly developed identification procedure illustrated in Figure (7).

The proposed procedure includes systematic steps that generate the same result of the visual method for identifying critical sequence introduced by Harmelink and Rowings (1998). This visual method states that critical sequence occurs where activities in consecutive processes are closest to each other. This method locates visually the least distance between preceding and succeeding processes to identify all critical activities. Unlike the visual method, the proposed procedure provides a systematic framework for identification of all possible critical chains as

shown in Figure (7). The critical links between two consecutive processes are located where SD of activity i in process $j+1$ equal FD of activity “ i ” in process “ j ” as presented in Equation (12).

$$SD_{i,j+1}(AG) = FD_{i,j}(AG) \quad (12)$$

i , the number of activity where $i=1 \dots n$

j , the number of activity where $j=1 \dots m$

n and m , numbers of activities and processes respectively

The identification procedure utilizes the onward and backward identification procedures; the onward procedure identifies all the critical links between process “ j ” and “ $j+1$ ” where i varies from 1 to n and then the backward procedure (Zhang et al 2013) is initiated to identify critical links between process “ j ” and “ $j+1$ ” when i varies from n to 1 as shown in Figure (7). Once all the critical links among processes are identified then a set of critical sequences can be generated using one critical link between two consecutive processes at a time until all the identified critical links are used at least in one critical sequence using the framework presented in Figure (7).

3.6 Adding feeding, resource and project buffers:

Both LSM and CCPM use buffers to absorb delays of activities due to uncertainty associated with productivity rates and resource availability. This fact facilitates the integration of both methods but it assigns the buffer types and positions used in LSM in accordance with CCPM rules. Traditional stage buffers used in LSM between different stages of work, and activity buffers are included in the estimated activity time to account for variability in productivity rates. However, in the proposed method, traditional buffers for LSM are replaced by CCPM feeding, resource and project buffers.

Peer (1974) illustrated that if linear schedules are balanced to the extreme, then all activities are critical. This indicates that assuming multiple critical sequences is valid. Hence each critical

sequence has different project buffer based on its variability. Project buffer is added at the end of critical sequence as per CCPM method, and in case of multiple critical sequences, each critical sequence should have different project buffer depending on its critical activities variability. In this case the project buffer is selected as the maximum buffer of all critical sequences and it is calculated using Equation (13). The feeding buffers are added based on CCPM to reduce the effects of delay of non-critical chains on critical chains. Feeding buffers in activity based scheduling are assigned between the critical chain and non-critical chain. Figure (8) illustrates the key features of CCPM scheduling in reducing activity durations, resolving resource conflicts, identifying critical chains, assigning buffers (resource, feeding and project), and managing buffer consumptions. Also, CCPM considers the buffers arising from the variability of “resource-critical activities” number D1, 2, 3 and F1, 2, 3, 4, 5 as shown in Figure (9). The delay of resource-critical activities delays part of the critical sequence and accordingly the project completion date. Hence, the feeding buffer should be assigned at the end of resource-critical activities and calculated using Equation (14). However, this causes discontinuity for activities and for this reason feeding buffers in this research is assigned at the end of activities with a value that accounts for variability of resource-critical activities. For example, activities D1, 2, 3 are resource-critical activities and feeding buffer is assigned after D6 and not after D3 to respect the continuity of activity D. Assigning project and feeding buffers at suggested locations fulfils complete integration of LSM and CCPM because it respects the rules of both methods. Project buffer is assigned at the end of critical sequence to absorb its variability. Feeding buffers are assigned after non-critical chains emerging into critical ones to absorb non-critical chains variability without delaying the project, while continuity of resources is maintained according to LSM.

Resource buffer included in current CCPM scheduling cannot be quantified and it acts as warning for shortages in controlling resources (Goldratt 1997). It is assigned before each activity on the critical chain that requires different controlling resource than its preceding activity. Resource buffers, however, are different than proposed RCB because the latter is quantifiable and it absorbs the delay of preceding activities due to variability of resources availability.

$$\text{Project Buffer} = \sqrt{\sum_{P=1}^{P=n} (D_P(\text{CL}) - D_P(\text{AG}))^2} \quad (13)$$

$$\text{Feeding Buffer} = \sqrt{\sum_{F=1}^{F=n} (D_F(\text{CL}) - D_F(\text{AG}))^2} \quad (14)$$

4 Case Example

The numerical example presented in this paper builds upon that of Selinger (1980) for a hypothetical three span reinforced concrete bridge that has four segments (units) with five repetitive processes in each segment as shown in Figure (10). These processes are excavation, foundation, columns, beams and slabs. This example was used by other researchers deterministically (Russell and Caselton 1988, Moselhi and El-Rayes 1993, Nassar 2005, Liu and Wang 2007) and stochastically by Bakry (2014). Bakry (2014) included the uncertainty by utilizing fuzzy duration function for activities which is transformed into a deterministic duration (Dur_{EV}) as shown in Table 2. Then another duration is assumed based on agreement index (AI) that is assigned by the user to assess the amount of uncertainty affecting the activity being considered to account for the user desired confidence in the produced schedule.

The proposed method is applied by assuming that $D_{i,j}(\text{AG}) = Dur_{EV}$ and $D_{i,j}(\text{CL}) = Dur_{AI=0.9}$ to illustrate the differences between the developed method and that of Bakry (2014). In this case

study, a triangular distribution is assumed for evaluating the duration of activities where Dur_{EV} is the mean/aggressive duration and $Dur_{AI=0.9}$ is the safe duration at 90 % of confidence. Bakry's method adds intermediate buffers at the point of contact of two critical activities as shown in Figure (11). However, CCPM method emphasized that "safety durations" are between activities. Though Bakry's approach focused on respecting activities continuity to the maximum by adding intermediate buffers to account for the variability of different activities that may cause unnecessary extended project duration. The proposed method was applied as shown in Figure (12). All the intermediate buffers were removed based on CCPM then two feeding buffers were added as shown in Figure (12) after columns and slabs activities. The first equals 2.2 days and it accounts for the variability of the first two resources-critical activities for columns process, and the second equals 1.8 days and it accounts for the variability of the first two resource-critical activities for slabs process. While the first three activities of beams does not have a feeding buffer because it has no variability in productivity rates. Then the project buffer of 5.45 days was added at the end of the critical sequence which is marked by dotted arrows on Figure (12). The project duration in Bakry's study was 163 days with buffers; however, the developed method led to 152.5 days including feeding and project buffers. Bakry's approach is reasonable for repetitive projects that require attention towards continuity of resources to maximize the learning curve effect and minimize equipment idle time. Assumed intermediate buffers absorb the delay of critical sequence. However, this delay may not happen, rendering intermediate buffers is redundant. The proposed method, however, overcomes the method introduced by Bakry (2014) since it implicitly allows for acceleration of construction schedule where applicable.

The developed method introduces another feature of identifying multiple critical sequences then to add feeding and project buffers. As an illustration for this feature, it was assumed that the

314 duration of the second activity $D_{i,j}$ (AG) of earthmoving is changed from 15.5 to 19.5 days while
315 $D_{i,j}$ (CL) changed from 16.6 to 20.5. A different critical sequence is shown in Figure (13) that
316 includes the second activity of earthmoving and excludes the first activity of foundation. Another
317 feeding buffer is added as well at the end of foundation activity to account for the variability of
318 the first activity of foundation with a value of 2.4 days. The project buffer changed as a result
319 from 5.45 to 5.56 days to account for the variability of the new critical sequence, and the new
320 project duration changed from 152.5 to 155.16 days. Accordingly, the project total duration is
321 155.16.

322 The constraining resource is another feature of the developed method to identify the longest
323 critical sequence constrained by resources while respecting resources continuity constraint. The
324 available output of controlling resources for each activity were assumed as shown in Table 3
325 with 50% and 90 % confidence rates. The total required resources output for all bridge sections
326 are calculated using the following equations.

327 Activities quantities are illustrated in Table 4 as well as the crew output/ productivity rate at 50%
328 and 90 % confidence rate (Bakry 2014). Using CPR (50%) and CPR (90%) the new activities
329 durations are calculated using equations 1 and 2, and then the new critical sequence is identified
330 using the developed method as shown in Figure (14). The changed critical sequence from that
331 shown in Figure (14) due to resources constraints in foundation, columns, beams and slabs
332 activities. The project buffer value and the total project duration changed also to 12.8 days and
333 254.26 days, respectively. The RCB is calculated to be 3.36 days, while the overlap due to
334 resources conflict is 6.73 days and the overlap due to resources quantities variability is 3.36 days.
335 RCB is allocated after the start of beams process as shown in Figure (14). In addition to RCB,
336 three resource buffers are assigned on the critical sequence which are shown as stars when

controlling resource changes from preceding to succeeding critical activity. These buffers are assigned at the start of first activity of foundation, last activity of columns, and first activity of slabs respectively in accordance with the CCPM theory.

It was assumed to calculate resources outputs using the following equations:

Total required gravel outputs = $0.77 \times$ Total foundation quantities.

Total required sand outputs = $0.4 \times$ Total columns quantities.

Total required reinforcing steel outputs = $100 \text{ kg} \times$ Total beams quantities.

Total required cement outputs = $350 \text{ kg} \times$ Total slabs quantities.

5 Discussion and conclusions

This paper introduces a newly developed method that integrates LSM and CCPM scheduling methods. The method is capable of (1) respecting the continuity constraint required by LSM, (2) reducing project duration using CCPM aggressiveness, (3) identifying multiple critical sequences which are constrained by controlling resources, and (4) allocating project buffer and feeding buffers at the end of the longest critical chains and between non-critical chains emerging into critical ones based on CCPM. It also introduces “resource conflict buffer” to account for delays that may occur due to variability in resource availability. The proposed method formulates the scheduling procedure that integrates LSM with CCPM, allocates buffers that considers the confidence level in durations, and identifies critical sequence in a systematic way that facilitates the automation of the proposed method.

This integration utilises the aggressiveness of CCPM to reduce project durations while respecting the resource continuity as in LSM. Constraining resources changes the critical sequence and project duration. It is important to identify multiple critical sequences that may change the

project duration based on variability of their respective critical sequence activities. The case example demonstrates the applicability and illustrates the key features of the proposed method in scheduling repetitive construction projects. However, further investigations may highlight potential improvements that may help to make the proposed method more generic and to facilitate its application on other types of projects. The future work is to integrate the developed method with a monitoring and control technique that identifies and control the potential discontinuities during the execution phase of repetitive construction projects.

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Table 1 Features of integration methods

Reference														
Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Deterministic	N	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N	N
Stochastic	Y	N	N	N	N	N	N	N	Y	N	Y	N	Y	Y
Optimized	N	Y	N	Y	N	N	Y	Y	N	Y	N	N	Y	N
Identify critical path for repetitive activities	N	N	N	N	Y	N	N	Y	N	N	Y	N	Y	N
Allow for interruptions	N	N	N	Y	Y	N	Y	N	Y	Y	Y	N	N	N
3D Visualization	N	N	N	N	N	N	N	Y	N	N	Y	N	N	N
Buffer modeling	N	N	N	N	N	N	N	N	Y	N	Y	N	Y	Y
Learning curve effect	Y	N	Y	N	N	N	Y	Y	N	Y	N	N	N	N
Typical activities only	N	N	Y	N	N	Y	N	N	N	N	N	Y	N	-
Considers cost & time constraints	N	N	N	N	N	N	Y	Y	N	Y	Y	N	Y	N
Domain of applications	Manufacturing of missiles	Bridges	High rise building	Bridges	General	General	Housing projects, bridges and Highways.	Highway construction	General	High rise building	General	General	Bridges and Highways.	General

(1) Schoderbek and Digman 1967. (2) Selinger 1980. (3) Laramée 1983. (4) Russell and Caselton 1988. (5) Russell and Wong (REPCON) 1993. (6) Suhail and Neale 1994. (7) El-Rayes and Moselhi (LSCHEDULER) 1998. (8) Hassanein and Moselhi (HWPLANNER) 2002. (9) Kankainen and Seppänen (DynaProject) 2003. (10) Ranjbaran 2007. (11) Seppänen (VICO) 2009. (12) Ammar 2013. (13) Bakry 2014. (14) Slorup 2014.

Table 2 DurEV and DurAI for Bridge segments (Bakry 2014)

Activity	Unit 1		Unit 2		Unit 3		Unit 4	
	DurEV	DurAI=0.9	DurEV	DurAI=0.9	DurEV	DurAI=0.9	DurEV	DurAI=0.9
Earthmoving	12.4	13.2	15.5	16.6	10.8	11.5	16.6	17.7
Foundation	19.5	21.9	20.3	22.9	17.8	20	16.9	19
Columns	19.1	21	15.8	16.9	22.5	25	18.6	20.3
Beams	15	15	16.3	16.3	17.8	17.8	14.1	14.1
Slabs	0	0	17.3	18.7	14.3	15.5	18.1	19.7

Table 3 Controlling resources availability.

Activity	Controlling resources	Available Resources output/ (50%) confidence	Available Resources output/ (90%) confidence	Total required resources output			
				Section 1	Section 2	Section 3	Section 4
Excavation	Excavators	3 excavators (23.33 ea. m3/day)	3 excavators (20 ea. m3/day)	1147	1434	994	1529
Foundation (m3/day)	Gravel	27	23.1	794.6	829.3	765.4	689.9
Columns (m3/day)	Sand	2.4	2.3	41.6	34.4	51.6	40
Beams (m3/day)	Sand	2.4	2.3	34	36.8	40.4	32
Slabs (kg/day)	Cement	2100	1750	0	48300	39900	50750

Table 4 Activities quantities and productivity rates.

Activity	Quantities (m3)				Average Crew Output	Crew Output	Crew Output due to constraining resources	Crew Output due to constraining resources
	Section 1	Section 2	Section 3	Section 4	PR (50%) m3/day	PR (90%) m3/day	CPR (50%) m3/day	CPR (90%) m3/day
Excavation	1147	1434	994	1529	92.29	86.52	70	60
Foundation	1032	1077	943	896	52.99	47.12	35	30
Columns	104	86	129	100	5.5	5	6	5.75
Beams	85	92	101	80	5.66	5.66	6	5.75
Slabs	0	138	114	145	7.98	7.36	6	5

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