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Application of Linear Scheduling in Water Canal Construction with a comparison of Critical Path Method

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Abstract

Critical Path Method (CPM) still remains the most commonly used scheduling technique, despite many studies confirming its shortcomings for scheduling repetitive construction projects. This research evaluated the case study of an alignment-based precast water canal erection project, which was originally planned with CPM and analysed the suitability of using Linear Scheduling Method (LSM) for the same project. The case study project was scheduled using both CPM and LSM tools and the results were compared in terms of estimated total duration and resource cost. The results showed that LSM produced a saving of 10 days in total duration and 20.07% in estimated resource cost over CPM. LSM also proved to be the better tool in terms of other schedule attributes like resource assignment, levelling, visualization etc. for alignment-based projects. LSM can be highly efficient for scheduling different types of repetitive construction and offers benefits like better workflow and continuous resource usage.

Keywords: Linear Scheduling Method; Critical Path Method; Scheduling; TILOS; Precast Construction.

INTRODUCTION

The fundamental trait of any project is to have a defined beginning and end in time, which makes it a temporary endeavour (Institute, 2017). Project Management Institute (PMI) specifies five broad components that constitute the life cycle of a project management process: (i) initiating, (ii) planning, (iii) executing, (iv) monitoring and controlling, and (v) closing (Institute, 2017).

These principles naturally apply for to managing construction projects, which is becoming a complex task every day due to increasing variables and uncertainties to be accounted for, especially during the planning stage. According to Yamín and Harmelink (Yamín and Harmelink, 2001), construction companies are trying to gain a competitive advantage by achieving more sophistication and specialization in executing specific types of construction. Managing specialized projects requires more intensive scheduling tools that need to be advanced than those typically used in the conventional projects. Project scheduling is principally a complex decision making process since it involves numerous activities and resource allocations that need to be optimized properly (Xu and Zhang, 2012).

The Critical Path Method (CPM) is a commonly used scheduling technique in construction which is deemed powerful for scheduling and using project control functions (Bansal and Pal, 2009; Kastor and Sirakoulis, 2009). CPM has its application in the construction industry since the 1960's (Burns, Liu and Feng, 1996) invariably in all kinds of projects (Hegazy, 2005; Shi and Blomquist, 2012). Using software systems for developing plans and schedules has become a prevalent practice in construction projects across the globe (Olivieri *et al.*, 2019). Software packages like Primavera, Microsoft Project, Asta Power Project etc. are commonly used for this purpose and all these packages follow CPM logic in schedule generation (Hegazy and Menesi, 2010; Bragadin and Kähkönen, 2016; Olivieri *et al.*, 2019). In a way, it is the popularity of these software packages that enabled the widespread use of CPM scheduling in construction (Olivieri, Seppänen and Denis Granja, 2018). However, the major criticism placed against CPM is that, it is not suitable for scheduling projects with repetitive activities (Harris and Ioannou, 1998; Hegazy and Kamarah, 2008; Koskela *et al.*, 2014) that will have long and exhaustive schedules (Jongeling and Olofsson, 2007; Lu and Lam, 2009). Many researchers have pointed out the limitations of CPM in generating continuous workflows (Arditi, Tokdemir and Suh, 2002; Olivieri, Seppänen and Denis Granja, 2018), balancing of crews (Russell, A.D. and Wong, 1993; Hamzeh, Zankoul and Rouhana, 2015) and continuous utilization of resources like material, equipment and labour required in a project with repetitive tasks (Mattila and Park, 2003; Benjaoran, Tabyang and Sooksil, 2015). Besides, the fact that same set of activities and information will be repeated in a project containing repetitive activities, a CPM schedule for such a project will get cluttered with the same information again and again (Ammar, 2019). This might result in a confusing project plan.

Repetitive projects occupy a significant share of global construction and meticulous project planning is an indispensable requirement for them. Repetitive projects may be defined as the continuous construction of multiple similar units (Ammar, 2019). Repetitive construction projects may be grouped into two categories: point-based projects (e.g. multi-unit housing projects, high rise buildings etc. that have vertical alignment) and alignment-based or distance-based projects (e.g. pipeline construction, highway projects etc. that have horizontal alignment) (Agrama, 2006; Duffy, 2009). According to (El-Rayes and Moselhi, 1998), the repetitive activities can be further categorized as ‘typical’ and ‘atypical’ activities. Typical category activities are assumed to have identical durations along with all units and atypical activities are assumed to have variable durations.

Linear Schedules (LS) are proved to be effective alternates for scheduling repetitive projects (El-Rayes and Moselhi, 1998; Arditi, Tokdemir and Suh, 2002). Among the commonly used variants of LSs, Line of Balance (LOB) or Vertical Production Method (VPM) is adapted for point-based projects and Linear Scheduling Method (LSM) is suited for distance-based projects (Yamín and Harmelink, 2001; Duffy, 2009). LSM is nothing but a graphical representation of the project activities with distance or location on one axis and time on the other axis. It can be defined as a visual representation of a repetitive project’s construction plan depicting the logic and relation between the activities of the project (Mattila and Park, 2003). LSM improves continuous workflow significantly better than CPM, controls the production and provides faster response to delays and interferences. Similar to CPM, where the activities on non-critical path contain floats after the critical path is determined, LSM too allows rate floats on its non-controlling activities or non-controlling segments, after evaluating the controlling activity path (Olivieri et al.,2019). Repetitive projects like pipelines, highway, canal projects etc. involve continuous and linear activities, which need to be constructed along the horizontal alignment of the facility. While scheduling these projects, CPM divides the whole process into discrete activities that are sequenced in order of their performance. However, the major concern in such projects is to assess and arrive the optimum production rates for the timely completion. LSM offers efficient scheduling of these projects by focusing on repetitive work activities and the production rates to identify any possible setbacks in the construction process (Matila and Park, 2003). In CPM, critical path is defined as the longest time-consuming path throughout the network, whereas in LSM, the controlling path is defined on the basis of the least time interval, coincidence interval, and the least distance interval between two consecutive activities. Harmelink (Harmelink,1998) developed a computerized linear scheduling model in conjugation with an AutoCAD-based program to identify the controlling activity path and compared the results with CPM. He concluded that LSM provides a realistic controlling activity path by considering changing constraints in buffers thus providing accurate production rate details of linear activities which couldn't be achieved with CPM.

The major focus points for LSM application in highway construction projects include determination of production rates, identifying activity interruptions, buffers, calendar considerations, and allocation of project resources. LSM also provides realistic and reliable information to plan the method of construction and nature of work, identifies the risks better than the bar chart thus helping to optimize the construction cost and time. LSM's most important benefit is the ease with which it transforms a comprehensive work schedule to location-based segments, thus making it easier to monitor the progress of the project's linear activities (Johnston,1981).

Despite its proven utility for planning repetitive construction projects, LSM doesn't find widespread application in real-world for various reasons (Agrama, 2011). One of the major reasons seems to be the contractual specifications in favour of CPM. In a survey conducted by Galloway (Galloway, 2006), more than 60% of the respondents confirmed contractual obligation as the reason to opt for CPM schedules for their projects. Other reasons for schedulers to prefer CPM over LSM in repetitive projects are better familiarity with CPM analysis, the existent popular software packages following only CPM logic, the legal validity of CPM in delays and claims due to contractual conditions and lack of awareness and training in using LSM (Yamín and Harmelink, 2001; Olivieri *et al.*, 2019).

The main objective of this study is to apply LSM in a real-time alignment-based repetitive construction project and also provide a comparison of adapting CPM planning for the same project in terms of perceived total duration and planned cost. A precast water canal construction project was chosen as a case study for this purpose and the erection schedule of the project was prepared using both LSM and CPM tools. The results of both these scheduling techniques are compared in terms of savings in total planned duration and estimated resource cost of the project.

BACKGROUND

Linear Scheduling Method (LSM)

Linear Scheduling Method (LSM) is a graphical technique used for scheduling projects with continuous resource utilization demand like roads, tunnels, pipeline construction etc. (Duffy *et al.*, 2012). The name "linear scheduling method" (LSM) is particularly denoted for scheduling horizontal repetitive projects that have linear geometrical alignment (Agrama, 2011). LSM represents the project activities in the form of a 2-D graphical chart with location or distance on one axis and time on the other. For alignment-based horizontal linear projects like road construction, the distance or location is represented on the horizontal axis and time on the vertical axis. For projects with vertical linearity like high-rise building construction, the axes are interchanged. Such linear schedules are usually termed as Vertical Production Method (VPM) or Line of Balance (LOB) method (Duffy, 2009). The controlling activity path in LSM is recognized based on the time-distance relationships among the activities, which is very similar to that of a CPM critical path (Harmelink and Rowings, 1998; Agrama, 2011).

Lucko (Lucko,2007) provided a Mathematical approach to understand the concept of LSM in a simplified manner in terms of singularity function has been described by using Macaulay brackets in a transportation project "widening of a segment located in Northern Michigan taking time and location as buffers.

$$(x-a)^n = \begin{cases} 0\, for\ x < a \\ (x-a)^n\, for\ x \geq a \end{cases} \qquad -\ (1)$$

$$\frac{d}{dx}(x-a)^n = n\,(x-a)^{n-1} \qquad -(2)$$

$$\int (x-a)^n\, dx = \frac{1}{n+1}(x-a)^{n+1} + C \qquad -(3)$$

Where x is variable, a is segment length that serves cut off value, n is the order of the activities and C is an integration constant. These singularity functions are effective as, they contain segments of different properties within one functional expression, can be differentiated and integrated using standard rules. They provide a reliable mathematical description for the discontinuous process. This technique is based on geometry and algebra which can be evaluated manually by project managers easily. An important factor while using this technique is to select buffer for example location, time as required by that project. Equations are evaluated in sequential order as LSM is flexible in relating the activities to each other and usually suffice to use a sequence with time and location buffers. This method can accommodate infinite segments of activities, each with their production rate requiring basics mathematical skills yielding complete and precise results for any linear schedule. This application replicates the intuitive nature extending the in-depth analysis of the graphical representation of a linear schedule beyond

CPM capabilities. In view of the differential section, this keeps the activities and their buffers mathematically intact throughout the analysis. In terms of singularity function, start and end times and their efficiency are simple and distinguished. (Lucko,2008).

Lucko and Orzco (Lucko and Orzco,2009) extended the concept of rate float by distinguishing its existence in terms of time and location buffer and combination of both. Float types can be calculated using singularity functions. These mathematical models described activities and their buffers over a continuous range. Float at any location can be determined accurately, equipping schedulers to assess the impact of delays on linear or repetitive construction projects. Rate float indicates possible changes in the production rate of a non-controlling activity to fall under the controlling activity path. To avoid this, a two-stage schedule model integrating LSM and constraint programming was developed for linear project resource-levelling (Tang et.al.,2014). Considering two concepts of rate float, the amount of work accomplished by a resource per unit time and amount of work that can be accomplished during unit time overall activities are optimized. As constraint programming strategies like backtracking, testing, the forward check is provided with no additional constraint is required for changing buffer making it a more flexible and quality model for linear scheduled projects.

While LSM has been existent for several years, it's application in real-time repetitive projects is comparatively limited. There are some evidences of LSM applications in highway, pipeline, residential and tunnel projects. In one of the earliest applications of LSM, Johnston (Johnston, 1981) applied LSM in a highway project using different line patterns like line, block, shaded and bar to represent the different activities involved in the highway construction process on the horizontal axis and time duration on the vertical axis. The schedule also included production rates, buffers, calendar consideration and resource allocations. Harris and Loannou used a modified LSM for scheduling a repetitive housing project and computed the controlling activity path duration based on the activity production rates (Harris and Ioannou, 1998). For a hypothetical bridge project scenario, Liu and Wang (Liu and Wang, 2007) attempted to create a constrained programming based LSM model. Duffy et al. (Duffy *et al.*, 2012) adopted LSM using the software tool *Velocity 1.0*, for scheduling a real-time pipeline project of 750 km long in the USA with varying production rates owing to different project variables. In one of the recent studies, Rzepecki and Biruk used a simulation method to schedule the repetitive activities of a multi-storey residential building (Rzepecki and Biruk, 2018). Table 1 provides the details of additional case studies across the world related to LSM application in different types of construction, identified through literature review. Some cases of LOB application are also mentioned to understand the practicability range of linear scheduling.

Table 1 Cases of LSM Application in Different Types of Construction Projects

Reference	Type of Construction	Project Details	Project Location	Mode of LSM Application	Software Tool Used	Benefits
(Andersson and Christensen, 2007)	Residential Apartment	11-storied residential building with 144 apartments and a total living area of 13,500 m^2	Denmark	Initial CPM schedule was converted into LSM schedule	Control™ 2005	Improved workflow and enhanced project control
(Jongeling and Olofsson, 2007)	Cultural Centre (Commercial)	6-storied building with a concert hall and a library containing two-storey underground parking garage	Lulea, Sweden	4D LOB schedule was prepared for the major construction elements using the existing 3D model	DYNAProject	Reduction of waste in construction process and ease of project update and rescheduling
(Song and Lee, 2012)	Pipeline	Laying of 30-inch pipeline for a distance of 130 miles	Houston, Texas, USA	Stochastic Linear Scheduling Method (SLSM) was applied to simulate the linear activities along with their constraints	Simphony	Simulation of corrective look ahead linear schedules based on actual project performance
(Liu *et al.*, 2013)	Tunnel	Railway tunnel of 897 metres length with curved walls and reinforced concrete lining	Western China	An algorithm with LSM logic was designed to schedule the tunnelling activities with their constraints	-	Standardisation of LSM in railway tunnelling process through real-time validation

(Tapia P and Gransberg, 2016)	Dam (Post-Construction)	Earthfill Dam of 5 million m^3 capacity	Borinquen Dam, Panama Canal, USA	As-built project data was converted into a single LSM chart for forensic claim analysis	TILOS	Forensically identified project data depicted via single LSM graph aided easy reference and support for the delay claim
(Sharma and Bansal, 2018)	Hill Road	Highway stretch of 12.632 km situated in a hilly terrain	Himachal Pradesh, India	LSM was applied as Location Based Planning (LBP) using Geographical Information System (GIS) for different sections of the proposed highway	ArcGIS with Python scripting	Using GIS for LBP is highly effective for planning variable production rates due to geographical variations
(Markiz and Jrade, 2019)	Bridge	Bridge containing a 200 ft spanned girder supported by a 40 ft. wide central interior Bent	Ottawa, Ontario, Canada	Constraint based simulated LSM was integrated with Bridge Information Management System (BrIMS) at the conceptual design stage	CSiBridge	Accurate project cost and time estimation and as early as the conceptual design stage itself

As also can be seen from Table 1, there are different software tools that have been used by different researchers for creating the time-distance representations of LSM schedules. Successful application of LSM requires a suitable software package for efficient calculation and schedule updating (Duffy, 2009). The functionality of these software programs varies on the level of scheduling and project control requirements. Some of these tools are either add-ins to the existing CPM based programs in the market or having only basic scheduling functionalities. For managing large repetitive projects, stand-alone LSM based tools integrated with additional project control functionalities are needed. In this regard, Kim et. al (Kim *et al.*, 2019) suggest a few integrated LSM based programs like *MAGNET Project, TILOS, and Vico Office for Time* that offer augmented functionality beyond basic scheduling.

They also did a comparative study of the above three software tools and concluded that TILOS offers all round project management functionalities including alignment-based scheduling, auto-update and tracking of activities, clash detection etc., and is better suited for repetitive civil engineering construction projects. TILOS also offers the advantage of creating the time-distance LSM diagram in a CAD-type interface and generating resource and cost data along with the linear schedule (Duffy *et al.*, 2012). Based on the above aspects, TILOS was chosen for modelling the continuous nature of the precast canal construction project using alignment-based linear scheduling.

The literature review reveals that LSM has the potential to be applied to a range of repetitive construction projects. But there are only limited attempts of LSM application in alignment-based repetitive construction beyond highway construction and there are no evidences for the application of LSM in the construction of a water canal, which involves horizontal repetitive activities. In this context, it was decided to investigate the application of LSM in a precast water canal construction project and do a comparison with adopting CPM for the same project.

CASE STUDY

Research Methodology

The principal aim of this research was to show the effectiveness of the LSM over CPM in scheduling any type of alignment-based repetitive project, for which a precast water canal construction project was chosen as the case study. A deductive research approach was adopted with the research goal of verifying the potential advantages that LSM offers over conventional CPM for the selected case study. The flow of this research study is shown in Figure 1 below.

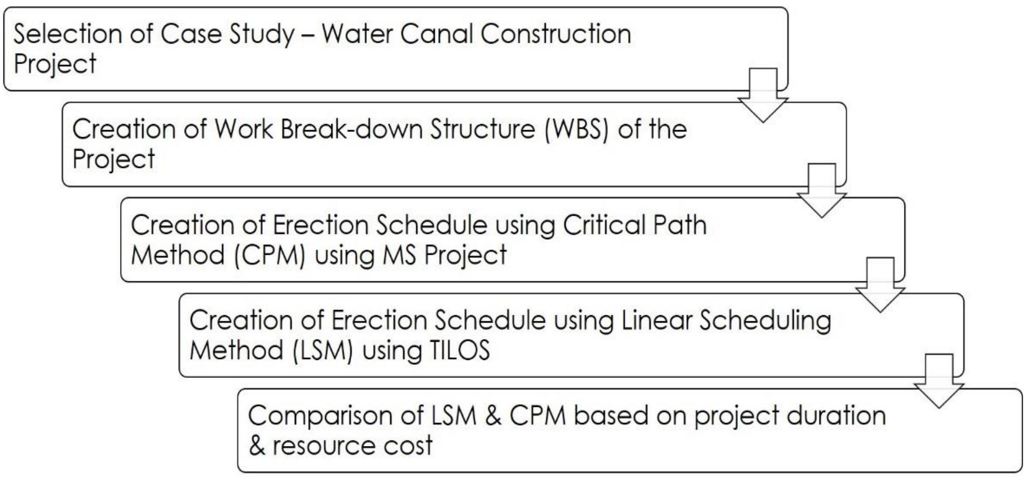


Figure 1 Research Methodology

A real-world water canal project to be built using the precast construction technique was selected as a case study to validate the application of LSM. It is basically a stormwater drainage canal to be located in Bengaluru, India. For the research study, construction of a major segment of the canal was considered which was about 184.32 m length. The plan view and section view of the canal structure are shown respectively in Figures 2 and 3.

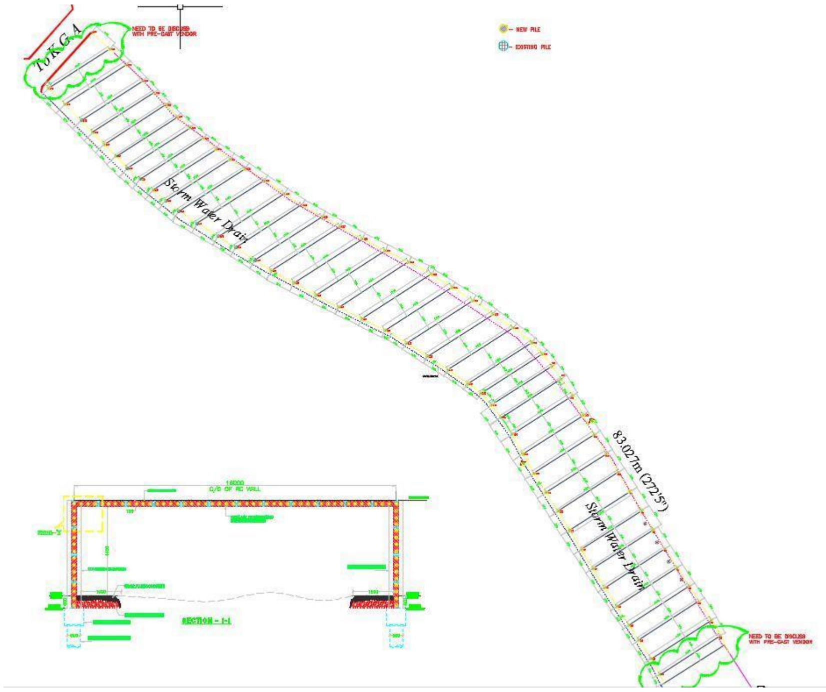


Figure 2. Plan View of the Water Canal

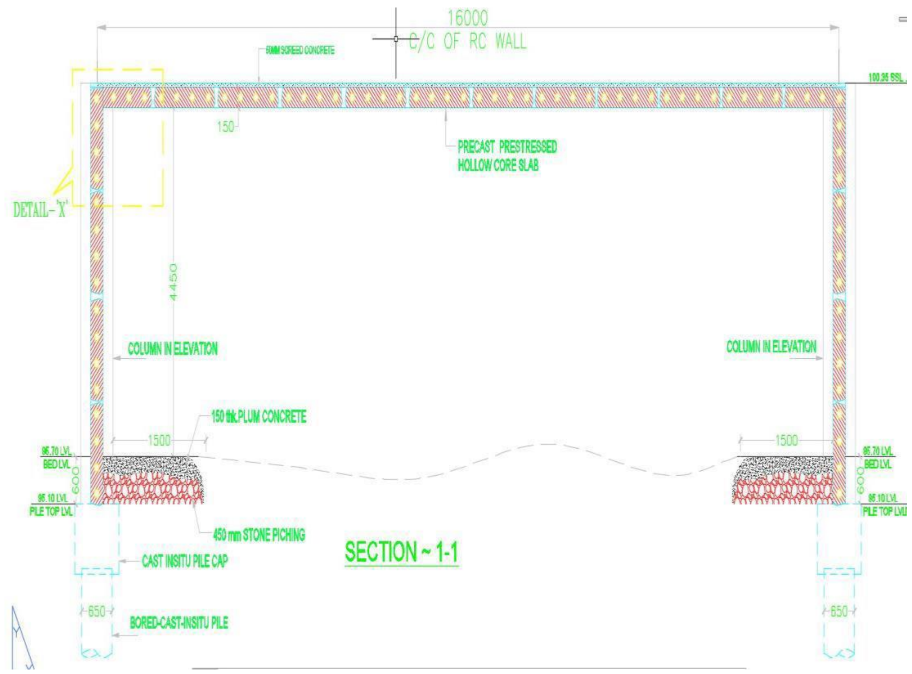


Figure 3. Section View of the Water Canal

The proposed water canal construction consisted of the erection of precast elements like column, beam, hollow core slab, side slab and roof slab. The dimensions, shape and alignment of the elements were designed by the consultant owing to the site conditions and specification requirements of the client. The number of precast elements to be erected for the canal construction included 84 columns, 42 beams, 328 side slabs and hollow-core slabs and 574 roof slabs; 1028 elements in total. The canal construction was divided into five zones viz., Zone A, B, C, D and E, for the ease of planning and coordination. The break-up of the number of elements to be erected in each zone is given in Table 2.

Table 2 Break-up of the number of precast elements in each zone

	Zone-A	**Zone-B**	**Zone-C**	**Zone-D**	**Zone-E**	**Total elements**
Columns	16	16	20	18	14	84
Beams	8	8	10	9	7	42
Side slabs and Hollow Core Slabs	64	56	80	72	56	328
Roof slab	112	98	140	126	98	574
Total elements per zone	200	178	250	225	175	1028

The project was at the initial planning stage when this study was taken-up. From the shop drawings of precast elements to be erected, the Work Breakdown Structure (WBS) of the project was formulated and the scheduling process was started. There were no contractual requirements to mandate the use of CPM schedule, but the contractor's planning team were originally set to adopt CPM schedule and were hesitant to go for LSM as they had less familiarity with the technique and its efficacy. So, we decided to schedule the project using both CPM and LSM parallelly, and do a comparison of the total planned duration and estimated resource cost to provide a convincing case for LSM.

For the comparison study, the following constraints were considered for both CPM and LSM schedules:

(i) Only resource loaded activities were taken.
(ii) The productivity of an individual resource was fixed and obtained from the standard productivity chart of the contractor.

(iii) The schedules were generated was based on parameters like total duration of each activity, maximum resource availability, the number of mobilizations and demobilizations needed and the number of activities and logic links.

(iv) Calendar and working hours were fixed. No overtime was considered.

(v) The additional allowance given for LSM schedule was that the sequence of locations could be conveniently changed, wherever it was not mandatory to follow the sequential order (for example, the sequence of structural erection tasks was not altered because they had to go in order).

Creation of Erection Schedule using Critical Path Method (CPM)

The precast canal erection for all the five zones was to be done on two bank sides that were named as KGA side and Century side. The WBS of the project is shown in Figure 4.

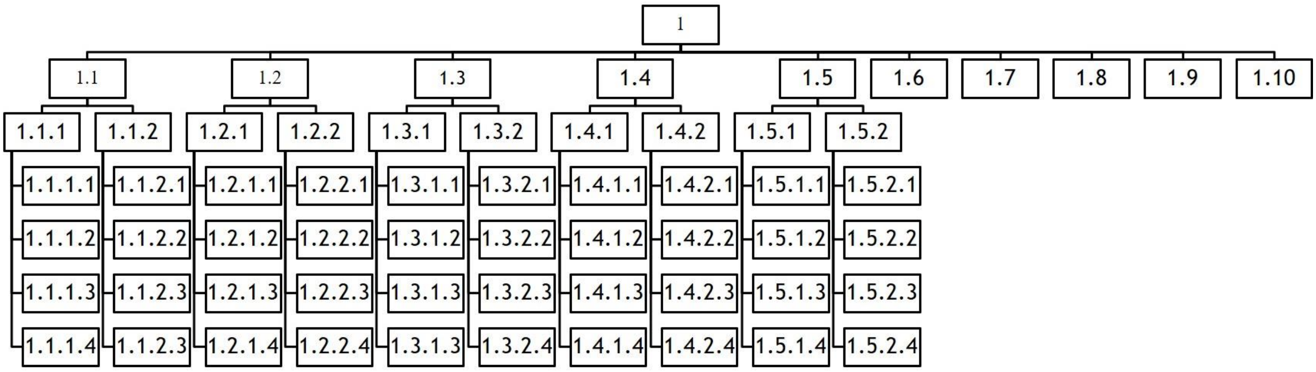


Figure 4 WBS of the Water Canal Project

Levels 1.1 to 1.5 of the WBS indicate the erection tasks for the 5 zones while 1.6 to 1.10 indicate the beam and roof slab erection and other finishing tasks. The sub-levels include the erection tasks for the two banks KGA side and Century side. From the WBS, the erection activities to be carried out on the two sides were arrived. The erection duration was calculated on the piece-count basis with the number of pieces erected per day was assumed based on historical data and expert opinion. Table 3 shows the list of activities, erection count and their durations.

Table 3 Activities, erection count and durations

Zone	Bank	Work	Element Per Zone	Element Per Days	Erection Days

1	KGA Side	Pile Concrete Work	8	5	1.6
		Column	8	10	0.8
		Side Slab and HCS	32	20	1.6
	Century Side	Pile Concrete Work	8	5	1.6
		Column	8	8	1
		Side Slab and HCS	32	20	1.6
2	KGA Side	Pile Concrete Work	8	5	1.6
		Column	8	10	0.8
		Side Slab and HCS	28	20	1.4
	Century Side	Pile Concrete Work	8	5	1.6
		Column	8	10	0.8
		Side Slab and HCS	28	20	1.4
3	KGA Side	Pile Concrete Work	10	5	2
		Column	10	10	1
		Side Slab and HCS	40	20	2
	Century Side	Pile Concrete Work	10	5	2
		Column	10	10	1
		Side Slab and HCS	40	20	2
4	KGA Side	Pile Concrete Work	9	5	1.8
		Column	9	10	0.9
		Side Slab and HCS	36	20	1.8
	Century Side	Pile Concrete Work	9	5	1.8
		Column	9	10	0.9
		Side Slab and HCS	36	20	1.8
5	KGA Side	Pile Concrete Work	7	5	1.4
		Column	7	10	0.7
		Side Slab and HCS	28	20	1.4
	Century Side	Pile Concrete Work	7	5	1.4
		Column	7	10	0.7
		Side Slab and HCS	28	20	1.4
1 To 5	-	Beam	42	8	5.25
1 To 5	-	Roof Slab	574	50	11.48

The erection schedule was created in Microsoft Project (MSP) by entering the activities, durations and other relationship related constraints. The project followed a 24-h working time with 2 shifts on weekdays and a half day working on Saturdays. Resources for the activities are assigned with their rates taken from Delhi Schedule of Rates Figure 5 shows the snapshot view of the activity and Gantt chart window and Figure 6 shows the resource allocation in MS Project.

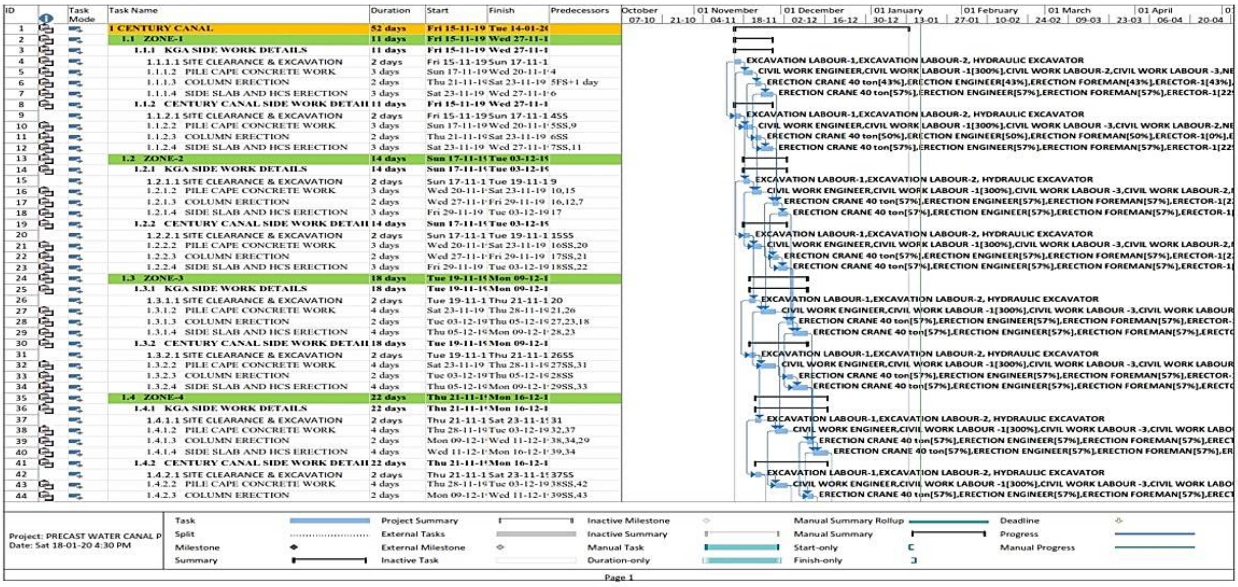
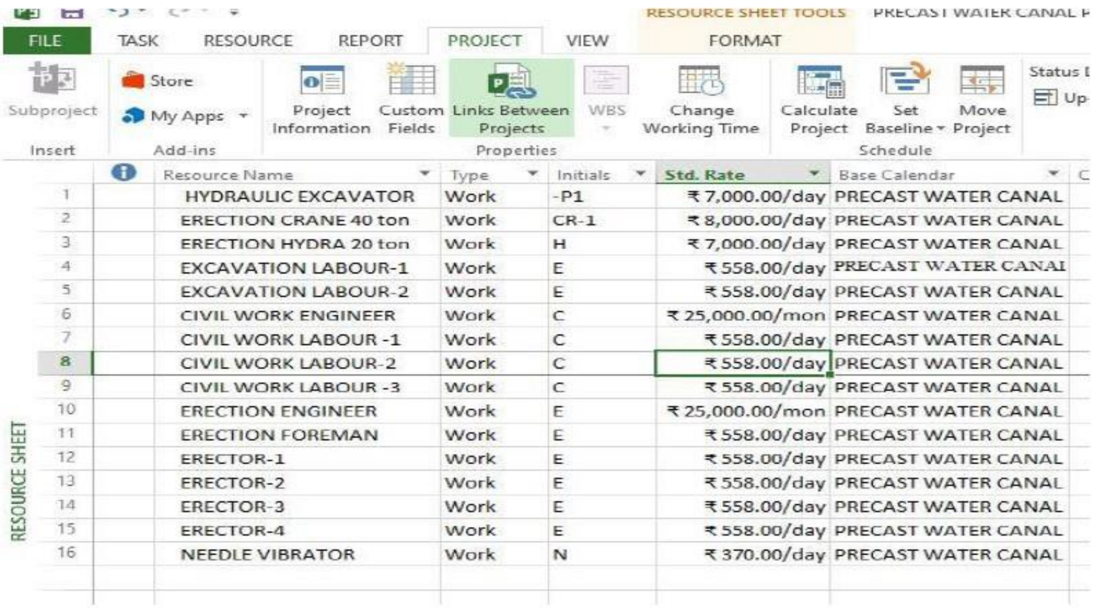


Figure 5 Activity and Gantt Chart View in MS Project



	Resource Name	Type	Initials	Std. Rate	Base Calendar
1	HYDRAULIC EXCAVATOR	Work	-P1	₹ 7,000.00/day	PRECAST WATER CANAL
2	ERECTION CRANE 40 ton	Work	CR-1	₹ 8,000.00/day	PRECAST WATER CANAL
3	ERECTION HYDRA 20 ton	Work	H	₹ 7,000.00/day	PRECAST WATER CANAL
4	EXCAVATION LABOUR-1	Work	E	₹ 558.00/day	PRECAST WATER CANAL
5	EXCAVATION LABOUR-2	Work	E	₹ 558.00/day	PRECAST WATER CANAL
6	CIVIL WORK ENGINEER	Work	C	₹ 25,000.00/mon	PRECAST WATER CANAL
7	CIVIL WORK LABOUR -1	Work	C	₹ 558.00/day	PRECAST WATER CANAL
8	CIVIL WORK LABOUR-2	Work	C	₹ 558.00/day	PRECAST WATER CANAL
9	CIVIL WORK LABOUR -3	Work	C	₹ 558.00/day	PRECAST WATER CANAL
10	ERECTION ENGINEER	Work	E	₹ 25,000.00/mon	PRECAST WATER CANAL
11	ERECTION FOREMAN	Work	E	₹ 558.00/day	PRECAST WATER CANAL
12	ERECTOR-1	Work	E	₹ 558.00/day	PRECAST WATER CANAL
13	ERECTOR-2	Work	E	₹ 558.00/day	PRECAST WATER CANAL
14	ERECTOR-3	Work	E	₹ 558.00/day	PRECAST WATER CANAL
15	ERECTOR-4	Work	E	₹ 558.00/day	PRECAST WATER CANAL
16	NEEDLE VIBRATOR	Work	N	₹ 370.00/day	PRECAST WATER CANAL

Figure 6 Resource Allocation in MS Project

Creation of Erection Schedule using Linear Scheduling Method (LSM)

The alignment-based erection schedule of the precast water canal was created using TILOS software application. The time-distance diagram of the linear schedule was created based on the geographical distance between the members in all five zones which was taken from the architectural plan drawing. Table 4 shows the geographical distance between the members in different zones.

Table 4 Geographical Distance between Canal Zones

Zone	ID	Distance in m	Total zone distance
Zone-A	1-2	2.682	32.483
	2-3	4.659	
	3-4	4.619	
	4-5	4.999	
	5-6	4.184	
	6-7	4.253	
	7-8	4.365	
	8-9	2.732	
Zone-B	9-10	4.689	33.331
	10-11	5.002	
	11-12	4.801	
	12-13	5.2	
	13-14	4.079	
	14-15	4.56	
	15-16	5	
Zone-C	16-17	3.933	40.463
	17-18	3.618	
	18-19	3.672	
	19-20	3.844	
	20-21	4.228	
	21-22	2.569	
	22-23	4.618	
	23-24	4.384	
	24-25	5.001	
	25-26	4.596	
Zone-D	26-27	3.678	43.095
	27-28	4.731	
	28-29	5.139	
	29-30	4.740	
	30-31	4.966	
	31-32	4.776	
	32-33	4.915	
	33-34	5.019	
	34-35	5.131	
Zone-E	35-36	4.955	34.974
	36-37	4.835	
	37-38	5.147	
	38-39	5.018	
	39-40	4.987	
	40-41	5.001	
	41-42	4.991	
Overall distance			184.34 m

TILOS has the inbuilt feature to automatically calculate the duration and work rate of the activities based on the geographical distance between them. The logic is that, the length of an activity is proportional to its quantity or the amount of work needed. So, the duration of the activity is also proportional to its length. In simple terms, the longer the distance of an activity is, the longer will be its duration. The project calendar, activities, constraints and resource allocations entered in TILOS were all the same as followed in MS Project. Figure 7 shows the resource allocation details and Figure 8 shows the activity list with work and duration parameters calculated by TILOS. The line type, pattern and colour help in differentiating the tasks according to their nature. The time distance diagram of the water canal project was generated with distance plotted on the x-axis at a unit interval of 5 meters and y-axis denoting the time at a unit interval of 2 days. Figure 9 shows the time-distance diagram of the project.

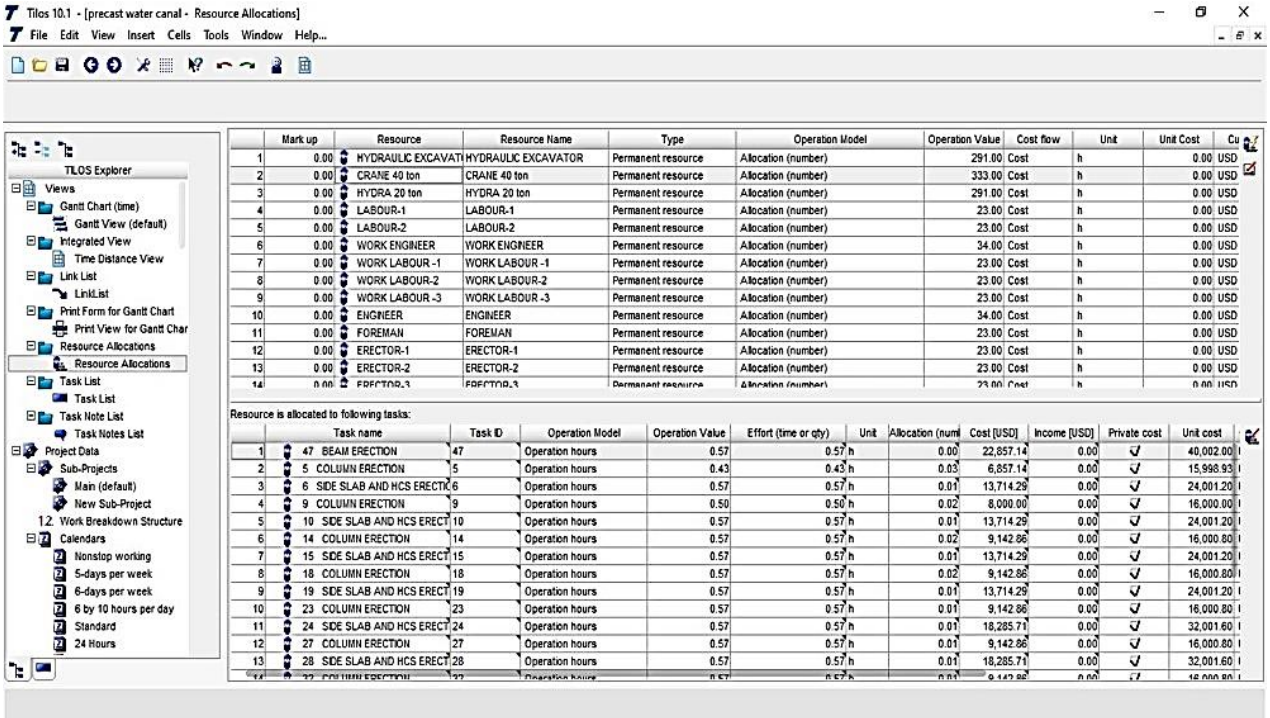
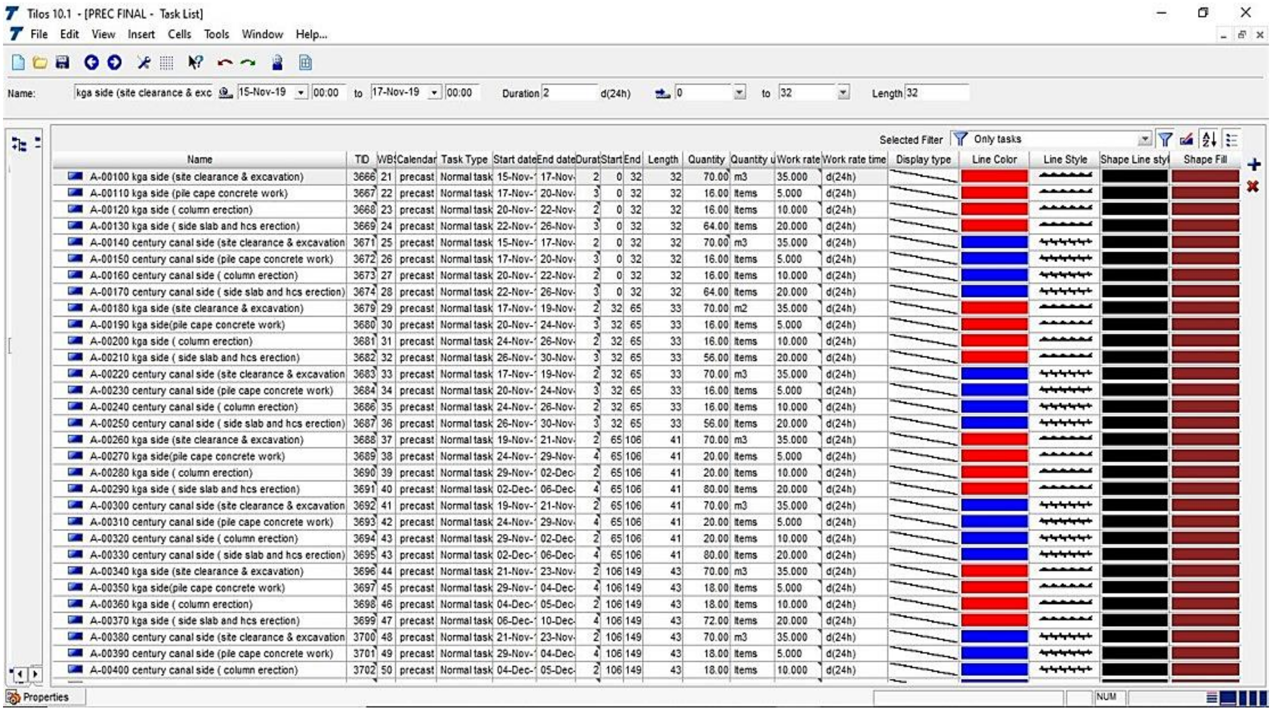


Figure 7. Resource Allocation in TILOS



Name	TID	WBS	Calendar	Task Type	Start date	End date	Durat	Start	End	Length	Quantity	Quantity u	Work rate	Work rate time
A-00100 kga side (site clearance & excavation)	3666	21	precast	Normal task	15-Nov-	17-Nov-	2	0	32	32	70.00	m3	35.000	d(24h)
A-00110 kga side (pile cape concrete work)	3667	22	precast	Normal task	17-Nov-	20-Nov-	3	0	32	32	16.00	items	5.000	d(24h)
A-00120 kga side (column erection)	3668	23	precast	Normal task	20-Nov-	22-Nov-	2	0	32	32	16.00	items	10.000	d(24h)
A-00130 kga side (side slab and hcs erection)	3669	24	precast	Normal task	22-Nov-	26-Nov-	3	0	32	32	64.00	items	20.000	d(24h)
A-00140 century canal side (site clearance & excavation	3671	25	precast	Normal task	15-Nov-	17-Nov-	2	0	32	32	70.00	m3	35.000	d(24h)
A-00150 century canal side (pile cape concrete work)	3672	26	precast	Normal task	17-Nov-	20-Nov-	3	0	32	32	16.00	items	5.000	d(24h)
A-00160 century canal side (column erection)	3673	27	precast	Normal task	20-Nov-	22-Nov-	2	0	32	32	16.00	items	10.000	d(24h)
A-00170 century canal side (side slab and hcs erection)	3674	28	precast	Normal task	22-Nov-	26-Nov-	3	0	32	32	64.00	items	20.000	d(24h)
A-00180 kga side (site clearance & excavation)	3679	29	precast	Normal task	17-Nov-	19-Nov-	2	32	65	33	70.00	m2	35.000	d(24h)
A-00190 kga side(pile cape concrete work)	3680	30	precast	Normal task	20-Nov-	24-Nov-	3	32	65	33	16.00	items	5.000	d(24h)
A-00200 kga side (column erection)	3681	31	precast	Normal task	24-Nov-	26-Nov-	2	32	65	33	16.00	items	10.000	d(24h)
A-00210 kga side (side slab and hcs erection)	3682	32	precast	Normal task	26-Nov-	30-Nov-	3	32	65	33	56.00	items	20.000	d(24h)
A-00220 century canal side (site clearance & excavation	3683	33	precast	Normal task	17-Nov-	19-Nov-	2	32	65	33	70.00	m3	35.000	d(24h)
A-00230 century canal side (pile cape concrete work)	3684	34	precast	Normal task	20-Nov-	24-Nov-	3	32	65	33	16.00	items	5.000	d(24h)
A-00240 century canal side (column erection)	3686	35	precast	Normal task	24-Nov-	26-Nov-	2	32	65	33	16.00	items	10.000	d(24h)
A-00250 century canal side (side slab and hcs erection)	3687	36	precast	Normal task	26-Nov-	30-Nov-	3	32	65	33	56.00	items	20.000	d(24h)
A-00260 kga side (site clearance & excavation)	3688	37	precast	Normal task	19-Nov-	21-Nov-	2	65	106	41	70.00	m3	35.000	d(24h)
A-00270 kga side(pile cape concrete work)	3689	38	precast	Normal task	24-Nov-	29-Nov-	4	65	106	41	20.00	items	5.000	d(24h)
A-00280 kga side (column erection)	3690	39	precast	Normal task	29-Nov-	02-Dec-	2	65	106	41	20.00	items	10.000	d(24h)
A-00290 kga side (side slab and hcs erection)	3691	40	precast	Normal task	02-Dec-	06-Dec-	4	65	106	41	80.00	items	20.000	d(24h)
A-00300 century canal side (site clearance & excavation	3692	41	precast	Normal task	19-Nov-	21-Nov-	2	65	106	41	70.00	m3	35.000	d(24h)
A-00310 century canal side (pile cape concrete work)	3693	42	precast	Normal task	24-Nov-	29-Nov-	4	65	106	41	20.00	items	5.000	d(24h)
A-00320 century canal side (column erection)	3694	43	precast	Normal task	29-Nov-	02-Dec-	2	65	106	41	20.00	items	10.000	d(24h)
A-00330 century canal side (side slab and hcs erection)	3695	43	precast	Normal task	02-Dec-	06-Dec-	4	65	106	41	80.00	items	20.000	d(24h)
A-00340 kga side (site clearance & excavation)	3696	44	precast	Normal task	21-Nov-	23-Nov-	2	106	149	43	70.00	m3	35.000	d(24h)
A-00350 kga side(pile cape concrete work)	3697	45	precast	Normal task	29-Nov-	04-Dec-	4	106	149	43	18.00	items	5.000	d(24h)
A-00360 kga side (column erection)	3698	46	precast	Normal task	04-Dec-	05-Dec-	2	106	149	43	18.00	items	10.000	d(24h)
A-00370 kga side (side slab and hcs erection)	3699	47	precast	Normal task	06-Dec-	10-Dec-	4	106	149	43	72.00	items	20.000	d(24h)
A-00380 century canal side (site clearance & excavation	3700	48	precast	Normal task	21-Nov-	23-Nov-	2	106	149	43	70.00	m3	35.000	d(24h)
A-00390 century canal side (pile cape concrete work)	3701	49	precast	Normal task	29-Nov-	04-Dec-	4	106	149	43	18.00	items	5.000	d(24h)
A-00400 century canal side (column erection)	3702	50	precast	Normal task	04-Dec-	05-Dec-	2	106	149	43	18.00	items	10.000	d(24h)

Figure 8. Task List with Work and Duration Parameters

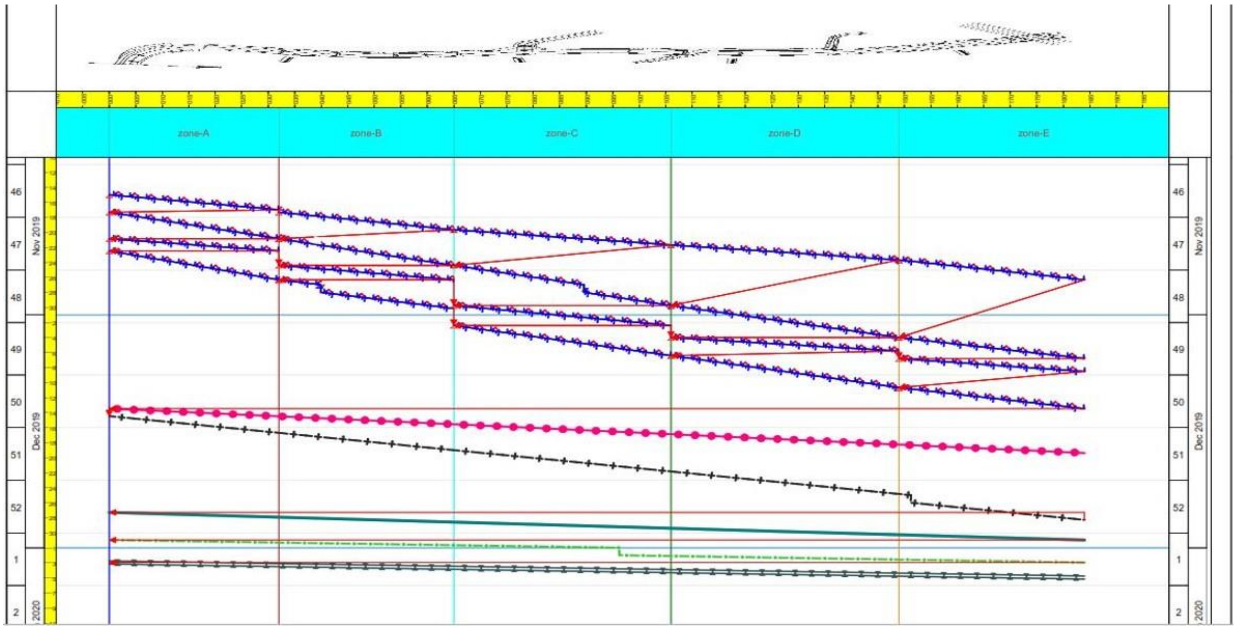


Figure 9. Time-Distance Diagram of the Water Canal Project

RESULTS AND DISCUSSION

Project Duration

The number of activities needed for the precast water canal erection was the same (45 activities) for both CPM and LSM schedules. But the total project duration as calculated using the CPM method was 52 days and the same project activities when modelled through LSM resulted in a total duration of 42 days. The convention of activity focussed predecessor successor relationship between the sequential precast segments was the basis of CPM duration calculation. Additionally, due to the logical constraints and varying production rates of the activities, waste time is created between a few activities which disabled the continuous workflow of the erection process. Hence, the project network demanded more duration when modelled with CPM planning. In the case of LSM, the geographical distance between the segments to be erected continuously was the basic consideration and as such the production rate of erecting segments was modelled based on their location in the erection plan. This enabled planning for a continuous workflow and avoidance of the waste time created due to CPM logical constraints, thus making the project duration as much as 10 days shorter in comparison with CPM planning. The problems of lack of workflow and substantial wasted time between activities with CPM and the evidence of better workflow with LSM have also been confirmed in the study conducted by Oliveri and his team (Olivieri, Seppänen and Denis Granja, 2018).

Estimated Resource Cost

Table 5 shows the estimated resource cost for both CPM and LSM schedules.

Table 5 Estimated Resource Cost - CPM Vs LSM

Resource	**Rate/day (INR)***	**CPM**		**LSM**	
		Resource Requirement in Days	**Resource Cost (INR)**	**Resource Requirement in Days**	**Resource Cost (INR)**
Hydraulic Excavator	7000	10	70000	10	70000
Erection Crane 40 ton	8000	45	360000	35	280000
Erection Hydra 20 ton	7000	45	315000	35	245000
Excavation Labour-1	558	10	5580	10	5580
Excavation Labour-2	558	10	5580	10	5580
Civil Work Labour-1	558	52	29016	42	23436
Civil Work Labour-2	558	52	29016	42	23436
Civil Work Labour-3	558	52	29016	42	23436
Erection Foreman	558	45	25110	35	19530

Erector-1	558	45	25110	35	19530
Erector-2	558	45	25110	35	19530
Erector-3	558	45	25110	35	19530
Erector-4	558	45	25110	35	19530
Needle Vibrator	370	52	19240	42	19530
Total Cost			9,87,998		7,89,658

*Rates according to Analysis of Rates for Delhi (2019)

The estimated resource cost in LSM is 20.07% cheaper than that of the CPM schedule. Except for the resources needed for excavation activity, all the resources of the LSM schedule take shorter durations than CPM schedule to complete the equivalent tasks. LSM achieves continuous workflow by synchronizing the activity durations based on the geographical distance between the erection tasks. This allows for continuous resource usage and avoidance of resource idling. The continuous workflow also reduces the mobilization and demobilization time of the resources which helps in lesser time consumption and faster completion of the task. In LSM, the resource scheduling is done on the basis of availability of the resource, which makes the resource levelling easier, so the resource levelling and scheduling go hand-in-hand. The resource allocation basically doesn't meddle with the work progression tasks. Whereas in CPM, resource scheduling for an alignment-based project such as precast water canal erection only considers the logical relationship of the tasks which makes it difficult to adjust the resources based on their availability. This resource assignment which relies on the succession of the task movement meddles with the work progression and warrants the requirement of resources for longer times. It is for these reasons, why the estimated resource requirement time and ensuing cost are substantially lower in LSM planning than in CPM.

Based on the observations made during the schedule development of the alignment-based water canal erection project, a comparison of how the different schedule attributes fared under CPM and LSM is presented below in Table 6.

Table 6 Schedule Attributes - CPM Vs LSM

Attribute	CPM	LSM

Schedule Representation	The schedule is represented as text and network diagram model. This does not provide the rate of progress of the alignment-based tasks	The schedule is represented as a time-distance graphical chart which enables easy understanding of the work flow. The entire schedule can be represented in a single page
Resource Allocation	The resource assignment relies upon the succession of the task movement, which meddles with the progression of the repetitive project tasks	The resource assignment is based on the location of the tasks which doesn't meddle with the work progression
Resource Levelling	The scheduling is completely based on dependency logic of the activities which cannot be altered on the basis of resource availability. Levelling might increase the cost in case of repetitive activities	The scheduling is done on the basis of geographical location of the tasks which considers the availability of resource. The resource levelling and scheduling are done simultaneously
Visualization	Geographical and graphical visualization of the project elements is not possible. Only theoretical information can be viewed which can be difficult to comprehend for repetitive projects like this water canal erection	The geographical site layout can be visually connected with the task schedule and viewed. All the project elements can be viewed in graphical format which makes the project plan more intuitive and easier to comprehend
Ease of Update	Updating project activities, durations, calendar etc. in CPM is conceivable. It is however, a tedious job and makes other aspects like resource allocation and levelling of the alignment-based tasks increasingly entangled	Any adjustments in project plan or calendar can be handily done and schedule can be readily refreshed

The key for effective implementation of LSM is dependent on its focus on certain important aspects of construction management. In this regard, a framework for effective implementation of LSM in repetitive projects is recommended as an outcome of this study, which is shown in Figure 10.

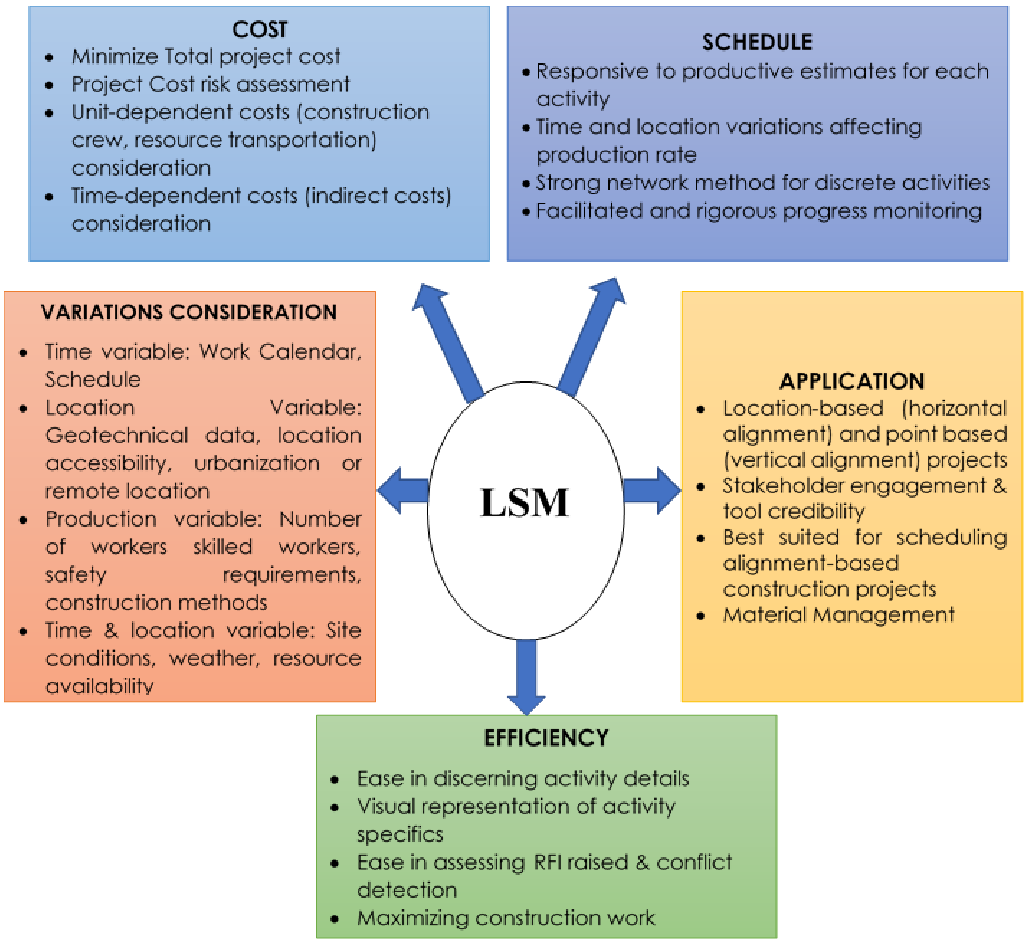


Figure 10 LSM framework for Construction Management

CONCLUSIONS

This study adopted two different scheduling methods for planning the erection of a precast water canal project and compared them based on their estimated project time and resource cost. The project schedule in CPM gave an estimate of 52 days to complete the erection process, while LSM schedule estimated 42 days which is 10 days i.e., 19.23% earlier than CPM. In terms of estimated resource cost also, LSM provided a savings of 20.07%. The study also found two important shortfalls of CPM viz. lack of continuous workflow and inability to schedule available resources for continuous work, but these problems were effectively resolved by LSM. LSM had the edge over CPM in terms of other schedule attributes like resource allocation, levelling, visualizations etc. for this case study project.

There are previous studies that explored the usage of LSM in repetitive projects like highways, residential buildings etc. but this research study considered the possibility of applying LSM in a precast water canal construction project and demonstrated that LSM can be the better planning tool for such projects in all aspects, where the conventional practice was to use CPM tool. But LSM usage is not common even in projects where repetitive elements are there, due to many reasons like lack of familiarity, training, contractual obligations and the perceived risk of using a new technique (Li-hui Zhang, 2015). For such projects, this analysis may be crucial in promoting LSM adaptation, suggesting that LSM is a convenient tool to learn and use. The significant advantage of LSM over CPM is its virtual-aided features and enabling effective communication among the project members. The fundamental limitation of the study is that only a small portion of the waterway construction was considered for testing the rationality of the LSM application. In addition, it must be analysed how influential LSM will be for a bigger quantum of work, where additional constraints such as fluctuating locations, unique activities and logical relationships, and variable production rates might play a role. Also, the LSM schedule in this study did not take into account the project control features like creating baselines, project updating, tracking etc. needed for future practical variations possible during execution, and it is to be seen that how those elements can be incorporated in the LSM schedule. The future studies could address the adequacy of LSM application for these specifications and expand the use of LSM to a variety of construction projects. As specified earlier, in spite of having a broader scope, LSM usage is not very widespread in construction and needs a rigorous campaigning initiative. To promote the usage of LSM in construction, more opensource linear scheduling software programmes need to be developed and academia should also step in to conduct extensive workshops and training to the industry professionals on effective usage of LSM in construction.

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