NEW TREND OF SCHEDULING IN LINEAR CONSTRUCTION PROJECT

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ABSTRACT : Scheduling is one of the main functions in construction project to determine the sequence of activities necessary to complete a project. The scheduling techniques provide important information crucial to a project's success. Highway construction project the paving activity can be considered a linear activity. Linear scheduling technique may be better suited for linear projects than other scheduling techniques. A new type of scheduling in linear project is calling Linear Scheduling Model (LSM). The Project monitoring and controlling is very ease to identify that all the stage of linear project and have more advantages.

Key words : CAP- Controlling Activity Path, CPM –Critical Path Method,, LSM –Linear Scheduling Model.

1. INTRODUCTION

Scheduling is one of the main functions in construction project to determine the sequence of activities necessary to complete a project. The scheduling techniques provide important information crucial to a project's success, it indicates which activities must be complete "as planned" if the project has to be "on time" and which activities have some flexibility. In scheduling terms activities that must be complete as planned are said to be critical.

Linear scheduling has long been regarded as techniques that provide significant advantages which are applied to linear construction project. Construction projects are divided into two main groups, one is linear such as highways, railroads, and pipelines and other one is nonlinear such as Buildings and multiple housing constructions

A linear project can be defined as a project where the majority of activities on the project are, "linear activities". Linear activities are those activities that are completed as they progress along a path. Highway construction project the paving activity can be considered a linear activity. Linear scheduling technique may be better suited for linear projects than other scheduling techniques. After several year of research on highway project in the Department of Transportation, Rowing and Harmelink (1993, 1994) done a research and developed an algorithm which determines the critical path in linear schedule. This algorithm, called the Linear Scheduling Model (LSM).

2. LINEAR SCHEDULING MODEL (LSM)

This LSM is applied to linear construction project. A linear project can be defined as projects where the major of activities on the project are "linear activities". Linear activities are those activities that are completed as the

progress along a path. LSM performs optimally when scheduling linear continuous project. LSM is inefficient when scheduling complex discrete projects. Here the identification of the critical activities or the controlling activity path (CAP) is done through an upward and downward pass through the activities alike CPM uses a forward and backward pass to identify the critical path. The CAP is significant in that, it provides a basis for analyzing linear schedules similar to CPM and allows for the development of functionality at a level commensurate with that found in CPM. The development of the CAP in the linear scheduling model makes CPM-type analysis of linear schedules possible. The CAP identifies which activities are controlling activities and which activities are non-controlling activities. Non-controlling activities, by definition must have float. In a linear schedule where the predominant factor determining duration is productivity, the concept of float needs to be redefined. The LSM calculate the "rate float" and it is impact as it application to the controlling activity path defined by the Linear Scheduling model.

3. DEVELOPMENT OF CONTROLLING ACTIVIY PATH (CAP)

An algorithm has been developed that is capable of determining the controlling activity path (CAP) in a linear schedule. This algorithm utilizes an upward and downward pass that identifies segments of activities that are no the CAP.

4. ACTIVITY TYPES

To understand the procedure for determining the controlling activity path in a linear scheduled it is necessary to be familiar with the different types of activities that appear on a linear schedule. Previous

research has suggested that there are three types of activities that can appear in a linear schedule. They are linear, block, and bar.

The linear activity type is divided into the following four specific subtypes
1. Continuous full-span linear (CFL)
2. Intermittent full-span linear (IFL)
3. Continuous partial-span liner (CPL)
4. Intermittent partial-span linear (IPL)

The block-type activity is divided in to the following two types

1. Full-span block(FB)
2. Partial-span block(PB)

Fig 1.0 shows all of the activity types, as they would appear on a linear schedule.

5. PROCEDURE

The procedure to determine the controlling activity path in a linear schedule involves the following steps:
1. Determine the activity sequence list
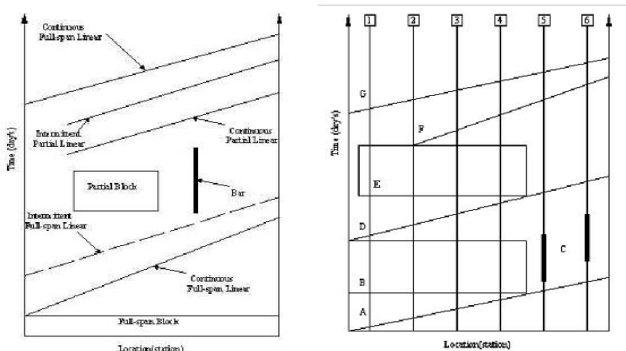2. Perform the upward pass
3. Perform the downward pass

Fig 1.0 Activity typesFig 2.0 Activity sequence paths

6. ACTIVITY SEQUENCE LIST

The activity sequence list identifies all of the possible logical sequence through the activities on a linear schedule. The controlling activity path is defined as the continuous path of longest duration through the project and defines the sequences of activities that must be completed as planned to finish the project within the overall planned duration. The activity sequence with the longest duration (or the least free time) contains all of the activities on the controlling activity path. The activity sequence list is the fundamental process in determining the controlling activity path in linear schedule and also provides a basis for the development of a computer algorithm.

The activity sequence list, although not location dependent, must describe the order in which activity will occur at any location on the project. Fig 2.0 shows a simplified example of a typical highway construction project. This project has three CFL activities A, D and G. Also assumed that there is a "0" time CFL activity at the beginning and at the end of the project. These activities are

called "start" and "end" intermediate activities. The activities that are not CFL activities will always lie between two CFL activities. For example, activity B and C, two bars (C) lie between CFL activities A and D, however at intermediate location (vertical line) between the CFL activities show the possible activity sequence through this sample liner schedule. Fig 3.0 shows the logical sequence of activities for this project the CFL activities span the entire project the five possible paths are represented schematically. As in CPM scheduling, the goal is to find the longest continuous path through this sequence of activities. This path will define the controlling activity path and determines when and where activities are controlling.
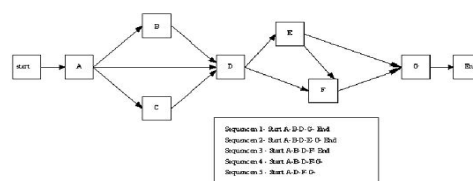

Fig 3.0 Logical sequence of Activities

7. UPWARD PASS

The goal of upward pass is to determine which activities or portions of activities could potentially be controlling. The process starts with the beginning of the project and progresses upward, identifying the path with the least free time between each pair of continuous full-span activities. In each case, the activity for which the potential controlling segment is being determined is designated as the origin activity. The origin activity will always be a CFL activity, and the earliest point in time on activity will be a CFL activity. The next CFL activity sequence list will be the target activity. The potential controlling segment of the origin activity can be determined by examining the relationship between these two activities. All other activity types other than CFL activities are with respect to the upper and lower bounding CFL activities.

1. Least-time (LT) interval: This is shortest time interval between any two consecutive activities. Consecutive activities are activities that can be connected in time (vertically) without crossing another activity. The LT interval will always occur at a vertex of the activities. For a linear activity, vertices occur at the endpoints or at any point where the rate of production changes. Vertices occur at the corners of box activities and at either end of bar activity.
2. Coincident duration: This is interval in time during which the two activities connected by LT interval are both in progress.
3. Least-distance (LD) interval: This is the shortest distance between the two activities that lies within coincident duration interval and intersects the LT interval.
Fig 4.0 shows an example of a pair of CFL activities for which the LT coincident duration and LD have been identified.
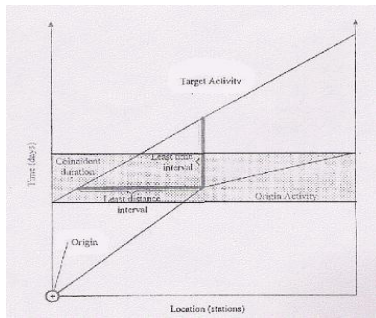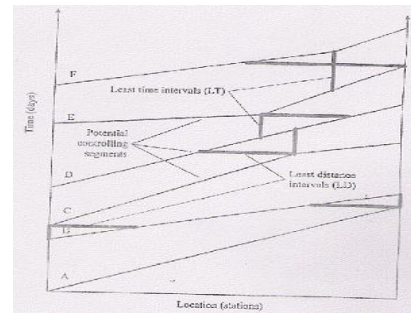
Fig 4.0 LT and LD
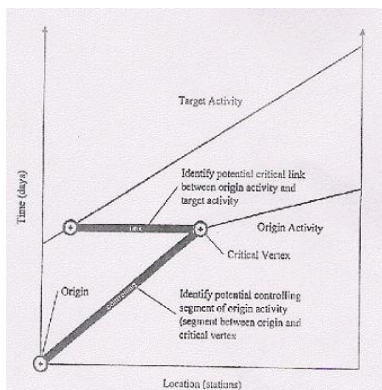

Fig 6.0 Upward Pass

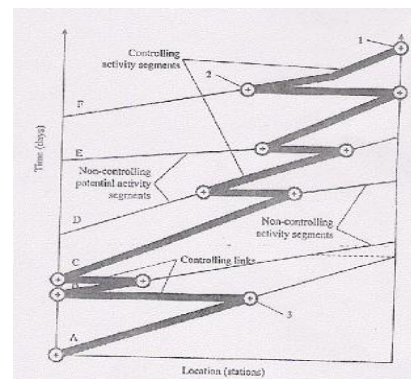
Fig 5.0 Potential Controlling Segment

Fig 7.0 Downward Pass

8. DOWNWARD PASS

The purpose of the downward pass is to determine which portions of the potential controlling segments are actually on the controlling activity path. This step can be compared with the backward pass used in CPM scheduling, which identifies activities that do not have any float. In the case of linear activity on a linear schedule, the downward pass identifies segments of activity for which the production rate cannot decrease without extending the duration of the project. This also means that the segments of activities not on the controlling activity path have rate float. An activity that has rate float potentially can progress at rate than planned without affecting the duration of the project.

To perform the downward passes start with the end of the last activity on the project. In this example, start point would be the end of activity F, as shown by point 1 in Fig 7.0. Next, follow activity F back in time, or downward on the linear point 2 .The segment identified by these two points determines the portion of activity F that is a controlling segment and the potential controlling link is now a controlling link. A controlling link is a point in time where the controlling activity path changes from one activity to another. Move horizontally to activity E along the critical link beginning at 3, and repeat the process performed on activity F to find the controlling segment on activity E. If, while moving back in time along an activity, the beginning of the activity is reached before a potential controlling link with a preceding activity is reached, a new critical link is established at the beginning of the activity.

9. RATE FLOAT CALCULATION

A linear activity on a linear schedule represents the planned start of the activity and anticipated rate at which it is planned to progress. Given this information and location that the activity is to cover, the end of the activity is determined. Any point on the linear activity(x, y) can be described as a location and time. The x coordinate represents a location and the y coordinate represent a time. Any two points on a linear activity (x_1 , y_1) , (x_2 , y_2) represent a segment of the activity. The slop of this line segment $(x_2 - x_1) / (y_2 , y_1)$ represents the rate at which the activity progresses in terms of units of location per units of time.

The least time interval, as defined in LSM, identifies points where the buffer between activities is at a minimum (Fig 8.0). Linear activities A and B are closed in time at point C this is for purpose of the model-the least time that should ever occur between these two activities and can be viewed as a point of intersection between the activities. In actual performance of the activities, the buffer may be reduced to something much less than the least time interval. Two activities cannot occupy the same space at the same time, now can they violate the logic defined by the sequence in which they occur at any location. Therefore, the least time interval is the minimum time that can occur between any two of defining rate float; two activities can never be closer than the least time interval.
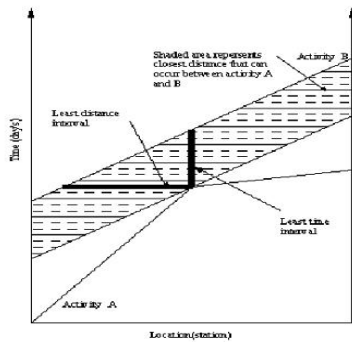
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Fig 8.0 LT Deter Minimum Buffer

9.1 Non-Controlling Activities

The only way that the rate of progress can occur at a rate lower than the planned rate for a beginning non-controlling segment is if the activity is started earlier than planned. The analysis of the beginning non-controlling activities on a linear schedule determines how much sooner an activity can reasonable be started and at what rate it can progress without affecting the overall project duration. The analysis of rate float in beginning non-controlling activities begins with the earliest activity in the group. In this case, the earliest activity is activity D-.the least time interval between any two activities defines how close these two activities can be at any location on the project. Point 1 on Fig 10.0 shows the original least time interval on the right, and assuming activity D- was to start earlier, it defines, on the left, how soon activity D- can start after activity C starts. Assume that the original start point of activity D- is $(x_{1D-}, y_{1D)}$ the end point is $(X_{2D-}, Y_{2D)}$ and the new earliest start time is $(X'_{1D-}, Y'_{1D)}$

In this case the lowest possible rate is

$$\left(\frac{(X_{2D-} - X'_{1D-})}{(Y_{2D-} - Y'_{1D-})} \right) =$$

Lowest possible production rate

The rate float for activity D- is the difference of the planned production rate and the lowest possible production rate.

$$\left(\frac{(X_{2D-} - X_{1D-})}{(Y_{2D-} - Y_{1D-})} \right) - \left(\frac{(X_{2D-} - X'_{1D-})}{(Y_{2D-} - Y'_{1D-})} \right) =$$

Rate float

In general, the rate float for any beginning non-controlling segment of a linear activity is

$$\left(\frac{(X_{2\alpha-} - X_{1\alpha})}{(Y_{2\alpha-} - Y_{1\varepsilon-})} \right) - \left(\frac{(X_{2\alpha-} - X'_{1\alpha-})}{(Y_{2\alpha-} - Y'_{1\alpha-})} \right) =$$

Rate float

Where α = any beginning non-controlling segment.

Beginning non-controlling linear activities only have rate float if they are started earlier than the time indicated on the linear schedule. The controlling activity analysis only identifies which activity segment could potentially be started earlier and progress at rate lower than that planned. If the contractor chooses to construct the projects as indicated on the linear schedule, in the beginning non controlling segments could potentially be viewed as controlling segments because, in effect, they progress at he planned rate to be the location when the activity controlling as indicated on the linear schedule. Also, the impact of not starting any beginning non-controlling activity as earlier as indicated by the earliest possible start time on subsequent activities must be carefully evaluated.

10. ENDING NON CONTROLLING SEGMENTS

The other portion of a linear activity where non-controlling segments can occur is at the end of the activity. This is an ending non-controlling segment. Fig 9.0 shows an example of several activities that have ending non-controlling segment, the end of the controlling segments: A+, B+, C+ and D+. On an ending noon-controlling segment, the end of the controlling segment fixes the start point of the segment. The fact end of the activity can be delayed lowers the rate at which the activity segment needs to progress. The amount that the production rate can be lowered defines the rate float for this activity segment. Note that there is a relationship between available float for subsequent activities that all have float. If all of the float is used upon an early activity, subsequent activities may have much less float available. This concept is analogous to total float in CPM.

As with beginning non controlling segments, ending non-controlling segments can occur in groups of one or more, bound by ending controlling activity segments or the start of finish activity on a project. Note that on Fig 9.0, the ending non-controlling segments A+, B+, C+ and D+ are bounded by the start of the project and the ending controlling segment E.
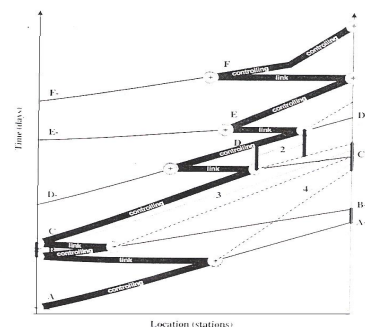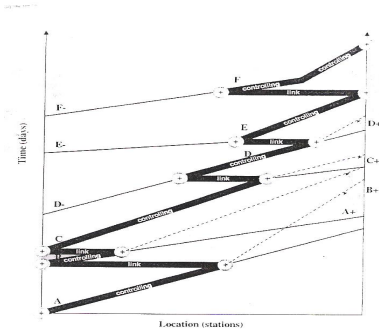

Fig 9.0 Rate in a series of

Fig 10.0 Maximum Rate Reduction Non-control

Activities in Ending Segments

If we assume that original start point of activity D+ is (x_{1D+}, y_{1D+}), the end point is (x_{2D+}, y_{2D+}) and the new latest end time is $(x^!_{2D+}, y^!_{2D+})$, the lowest possible production rate is

$$\left(\frac{(X^!_{2D+} - X_{1D-})}{(Y^!_{2D+} - Y_{1D-})} \right) =$$

Lowest possible production rate

The rate float for activity D+ is the difference between the planned production rate and lowest possible production rate.

$$\left(\frac{(X_{2D+} - X_{1D+})}{(Y_{2D+} - Y_{1D+})} \right) - \left(\frac{(X^!_{2D+} - X_{1D+})}{(Y^!_{2D+} - Y_{1D+})} \right) =$$

Rate float

In general, the rate float any non-controlling segment of a linear activity is

$$\left(\frac{(X_{2\beta} - X_{1\beta})}{(Y_{2\beta} - Y_{1\beta})} \right) - \left(\frac{(X_{2\beta} - X^!_{1\beta})}{(Y_{2\beta} - Y^!_{1\beta})} \right) =$$

Rate float
Where β = any end non controlling segment.

11. APPLICATION OF LINEAR SCHEDULING

Linear scheduling is applied Many projects such as the
  ➢ Construction of road
  ➢ Pipelines
  ➢ High-rise buildings
  ➢ Canal
  ➢ Runways
  ➢ Railways
  ➢ Tunnel

Table 1. Section -1(0.0 KM to 5.0 KM) road work data

Si. No	SECTION - 1 (KM 0.000- 5.000)		From 0.0 KM Starting date	To 5.0KM Finishing date
	Description	days		
	EXISTING TWO LANE	156 days	3/1/2003	8/29/2003
1	EARTH WORK	75 days	3/1/2003	5/27/2003
2	SUBGRADE	75 days	3/15/2003	6/10/2003
3	SUB - BASE (GSB)	75 days	3/20/2003	6/14/2003
4	WMM	75 days	4/1/2003	6/26/2003
5	DBM	70 days	4/15/2003	7/4/2003
6	BC	25 days	8/1/2003	8/29/2003

12. CALCULATION EXAMPLE
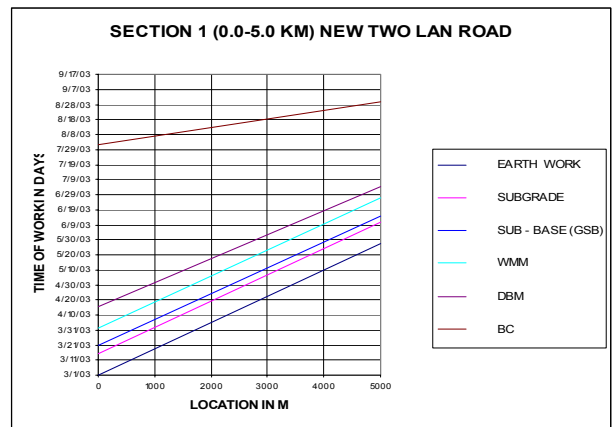

Fig 11.0 linear scheduling Model for Section 1 0.0KM-5.0KM

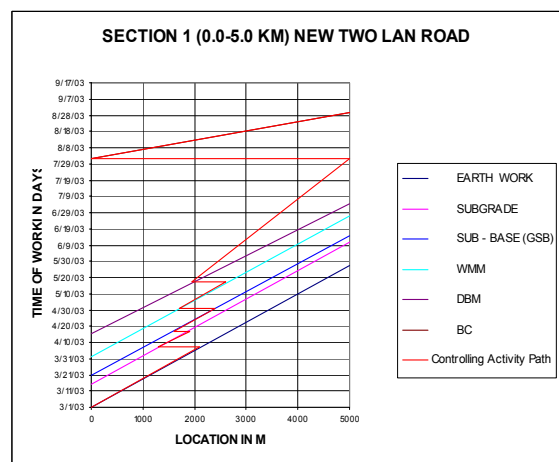**Fig 12.0** Controlling Activity Path in section 1 0.0KM-5.0 KM

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Table 2.0 Float Calculation Section -1(0.0 KM to 5.0 KM)

Activity	X_1	Y_1	X_2	Y_2	$X^!_1$	$Y^!_1$	Anticipated Rate M/day	Lowest possible Rate M/day	Rate float M/day
EARTH WORK	1400	25	2100	35	2600	45	70.00	50.00	20.00
SUB GRADE	1300	35	1900	45	2600	59	60.00	50.00	10.00
SUB – BASE (GSB)	1600	45	2400	59	3000	73	57.14	42.85	14.28
WMM	1700	59	2600	75	3400	95	56.25	40.00	16.25
DBM	1200	63	1950	75	2600	91	62.50	40.625	21.875
BC	1000	155	1600	165	__	__	60.00	__	__

1. Anticipated Rate $\quad = \left(\dfrac{(X_2 - X_1)}{(Y_2 - Y_1)} \right)$

2. Lowest possible Rate $\quad = \left(\dfrac{(X_{2D-} - X^!_{1D-})}{(Y_{2D-} - Y^!_{1D-})} \right)$

3. Rate Float $\quad =$

$$\left(\dfrac{(X_{2D-} - X_{1D-})}{(Y_{2D-} - Y_{1D-})} \right) - \left(\dfrac{(X_{2D-} - X^!_{1D-})}{(Y_{2D-} - Y^!_{1D-})} \right)$$
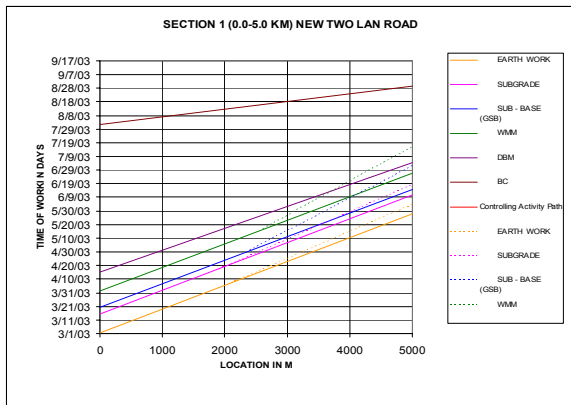

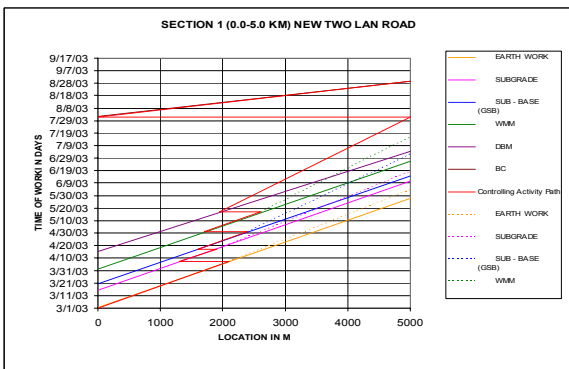**Fig 13.0** Section -1(0.0 KM to 5.0 KM) finishing time changed

Fig 14.0 Section -1(0.0 KM to 5.0 KM) scheduling float changes

13. RESULT DISCUSSION

Applied the Linear Scheduling Model in National Highway 46 Krishnagiri-Vaniyambadi Widening to 4-Lane Rehabilitation of existing 2-Lane Carriage way from Km.0.000 to Km.50.113

- The duration of project is 863 days in CPM and the same is reduced to 653 days in LSM
- The total cost of the project cost is 4 Million US$ including an indirect cost is 1 Million US$ which is reduced up to 24% (0.25 Million US$)
- Compare to the CPM , LSM has more Advantages
- From the graphical LSM we are monitoring projects day to day and control the complete project
- From the LSM we update the project progress and compare as per the scheduling work day by day

14. ADVANTAGES OF LINEAR SCHEDULING

- LSM is very easy to understand, and it can be used at every level of the construction project
- This capability allows PM to accurately plan activities both in time and location.
- It can be used at all levels of the company (managers, superintendents and crew).
- Updating LSM is simpl
- Linear schedules can be used as as-built documents for claim purposes or for historical productivity databases

15. CONCLUSION

Linear scheduling provides a mean to describe the logic of a linear construction project. The controlling activity path can be determined. Unlike CPM, the location at which and changes from non-controlling to controlling can occur at any point along the linear schedule. This capability provides a much more realistic Controlling Activity Path for linear activities. In linear scheduling, an activity's primary attribute is its production rate. As such, for float to be meaningful for a linear activity, it must be reflective of the activity's major characteristic. Rate float captures this characteristic and presents information to construction planers and managers in terms that are meaningful for linear projects. Linear projects, the LSM determination of controlling activities and rate floats provides information unobtainable with CPM. The integration of a controlling activity path and float in LSM has the potential for making technique ideally to planning and managing linear projects.

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