FORENSIC DELAY ANALYSIS OF LINEAR PROJECTS

Using Linear Scheduling Methodology tools to simplify forensic delay analysis for dispute resolution

Dimitrios Tousiakis, Director, HKA

INTRODUCTION

Clear presentation when demonstrating a fact in construction dispute proceedings is essential. It can dictate the outcome of a dispute and applies equally to claim submissions and any independent testimony required in Court, Arbitration or other formal proceedings.

Because of the complexities arising in delay analysis and its terminology, it is often characterised as a "dark art". A simple presentation of a sound methodology arriving at clear and persuasive conclusions, goes a long way to demystify this so called "dark art".

The nature of the construction project and the details of the dispute usually dictate the most appropriate delay analysis method to be applied.

Here, two fundamental scheduling methods are examined for their application to projects of a "linear" nature (such as roads, bridges, tunnels, etc.):

- The Critical Path Method ("CPM"); and
- The Linear Scheduling Method ("LSM").

CPM is a scheduling method that is more widely used for construction programme development and management.

However, for linear projects, the lesser known LSM is a more informative approach. This methodology uses graphical representation in a two-dimensional (2D) diagram within time and location axes.

In this article I review the potential and benefits of LSM graphs for the purposes of forensic delay analysis of linear construction projects. A hypothetical case study is used to demonstrate how as-built information can be incorporated into the LSM graphic to demonstrate the various project parameters, the actual progress of works, and the cause and effect of delay events.

WHAT IS A LINEAR PROJECT?

"Linear project" is the term that characterises a construction project with longitudinal, spatial and repetitive construction activities. Examples of linear projects are highways, pipelines, bridges, railway track systems and tunnelling.

The main characteristics of linear projects are:

- Repetitive identical activities along the length of the project (for highways, pipelines, etc.),
- Repetitive activities carried out irrespective of location and without a dependency on any particular spatial sequence. For example, if one section of a pipeline is temporarily inaccessible, work might still progress along other sections;
- The timely completion of linear projects is highly dependent upon efficient productivity rates and optimum resource utilisation for repetitive activities.

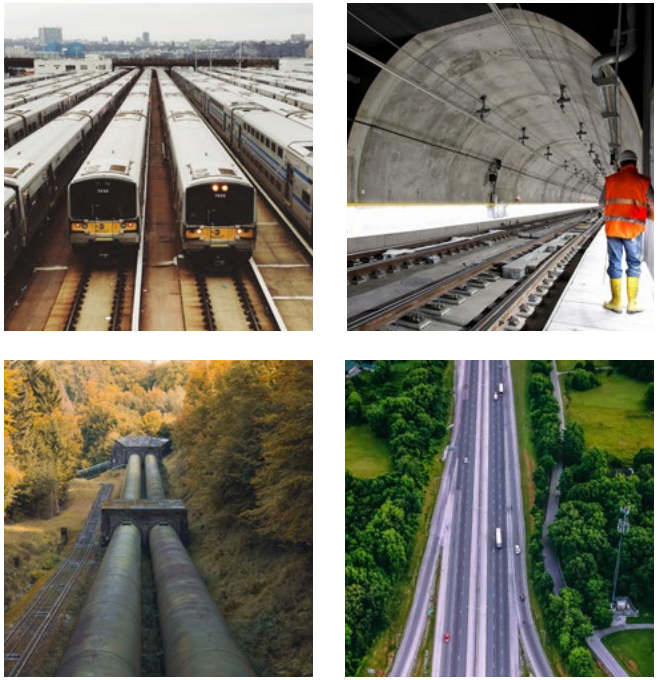

Figure 1 – Examples of typical linear projects (i.e. railway, tunnel, pipeline and highway projects)

CPM VS LSM

The CPM and the LSM are both scheduling and programming methods used for developing, managing and monitoring the time aspect of construction projects.

CPM

The Delay and Disruption Protocol published by the Society for Construction Law[1] describes the CPM programming method as:

"*The methodology or management technique that, through the use of calculation rules (usually automatically carried out by programming software), determines the critical path and calculates float.*"

CPM is the most commonly known and used scheduling method in construction management. Schedules are prepared by inputting data for individual activities (i.e. durations, dates, logic relationships, dependencies, etc.) into proprietary programme software tools. The software then applies algorithms to calculate free float, total float, critical and near critical paths for the combined elements of the project.

CPM is a valuable tool that can display graphical visualisations, normally in the form of a Gantt Chart.

However, because CPM focuses primarily on the time aspect of construction projects, the outcome is a one-dimensional (1D) overview. Caution is required when using this scheduling methodology because several important elements are not factored into the process.[2]

For example:

1. Spatial analysis and the constraints/parameters of the physical layout of the site are not automatically considered. CPM algorithms work on activity and relationship inputs and rely on the planner to avoid conflicting spatial requirements on site;
2. Optimum productivity rates for construction elements activities are not visually demonstrated in typical CPM graphs; and
3. Resources requirements, availability, cost, productivity levels and continuity of work are not visually demonstrated in typical CPM Gantt Charts.

An example of a typical CPM graph (Gantt Chart) is presented in Figure 2.

LSM

LSM is a graphical method, the output of which is a two-dimensional (2D) diagram that depicts both time and space in one chart.

Unlike CPM which is activity-focused, LSM is production-focused. Individual activities are represented by single lines on a chart, whose gradient is proportional to the rate of productivity. Thus, the graphical output shows the combined relationship between duration and output at a particular time and in a particular location.

The use of LSM enables:

1. Avoidance of impact from space restrictions on site;
2. Optimum productivity of all activities, ensuring that one activity does not adversely impact upon production rates of another; and
3. Continuity/uninterrupted working of resources.

The LSM methodology is particularly suitable for application to projects with a longitudinal or spatial dimension, or where repetitive activities occur and optimum productivity rates are essential to achieve timely completion.[3]

LSM graphs display two axes; one for time and the other for location, with data symbols depicting:

1. Activity lines with different styles to identify different activities or resource crews (for example, the excavation activity of a road project). The gradient of each activity line depicts the productivity rate of that activity;
2. Bars depicting an activity or constraint at a specific location for a specific period of time (for example, construction of culverts at specific locations of a road project); and
3. Blocks depicting an activity or constraint at a wide area of the site arising for a specific period of time (for example, areas of restricted access).

An example of a typical LSM graph is presented in Figure 3.

Additional information can be added to LSM graphics to enhance the overall picture. This may include the site's profile section drawing or the number of available resources at any given time and other relevant information.

"CRITICAL PATH METHOD ("CPM"): AN ACTIVITY-BASED SCHEDULING METHOD THAT FOCUSES STRONGLY ON THE TIME ASPECT PROVIDING ONE-DIMENSIONAL (1D) REPRESENTATIONS.

LINEAR SCHEDULING METHOD ("LSM"): A PRODUCTION-BASED SCHEDULING METHOD PROVIDING TWO-DIMENSIONAL (2D) DIAGRAMS DEPICTING TIME AND SPACE IN THE SAME CHART".

[1] SCL Delay and Disruption Protocol 2nd edition – February 2017, Appendix A (p. 62)

[2] This applies to the typical CPM scheduling via Gantt Charts. More recent CPM methods have been developed which can consider both space and time (for example 4D scheduling) but are not widely used and require proficient use of advanced and sophisticated software.

[3] Some examples of published scheduling methodologies which address similar objectives but with different terminologies are: Methodologies for unitary projects or work elements (floors, houses, apartments, stores, or offices), include: • Line of Balance (LOB) (O'Brien 1969; Carr and Meyer 1974; Halpin and Woodhead 1976; Harris and Evans 1977); • Construction Planning Technique (CPT) (Peer 1974; Selinger 1980). For longitudinal projects (highways, pipelines, tunnels, etc.), published methodologies include: • Time Versus Distance Diagrams (Gorman 1972); • Linear Balance Charts (Barrie and Paulson 1978); • Velocity Diagrams (Dressler 1980); • Linear Scheduling Method (LSM) (Johnston 1981; Chrzanowski and Johnston 1986; Russell and Casselton 1988).

A comparison between CPM and LSM graphs is pictured in Figures 2 and 3 below and shows the construction works of a theoretical pipe-laying linear project, including the construction of a culvert and a site access restriction.

The CPM graphical visualisation is in the form of a Gantt Chart. Time is depicted along the horizontal axis with the activities depicted in the form of bars.

By comparison, the LSM graphical visualisation uses a two-dimensional graph showing time on the vertical axis, and location on the horizontal axis, (i.e. a steeper line reflects a slower activity).[4]

Activity Name	Start	Finish
Excavation Works	20-Feb-19	02-Mar-19
Excavation (Area A)	20-Feb-19	24-Feb-19
Excavation (Area B)	20-Feb-19	24-Feb-19
Excavation (Area C)	26-Feb-19	02-Mar-19
Pipe Laying Works	22-Feb-19	08-Mar-19
Pipe Laying (Area A)	22-Feb-19	28-Feb-19
Pipe Laying (Area B)	27-Feb-19	05-Mar-19
Pipe Laying (Area C)	02-Mar-19	08-Mar-19
Backfilling Works	28-Feb-19	13-Mar-19
Backfilling (Area A)	28-Feb-19	05-Mar-19
Backfilling (Area B)	05-Mar-19	10-Mar-19
Backfilling (Area C)	08-Mar-19	13-Mar-19
Culvert Construction Works	25-Feb-19	28-Feb-19
Culvert Construction (Ch. 1+600)	25-Feb-19	28-Feb-19
Site Restrictions	20-Feb-19	27-Feb-19
Restricted Access (Ch. 2+400 - 2+800)	20-Feb-19	27-Feb-19

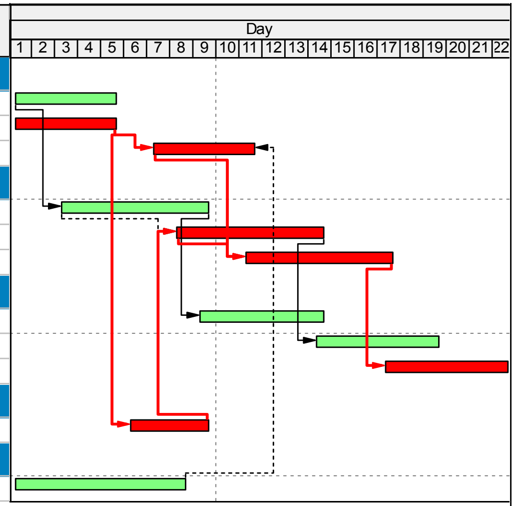

Figure 2 - Example of typical CPM graphical visualisation

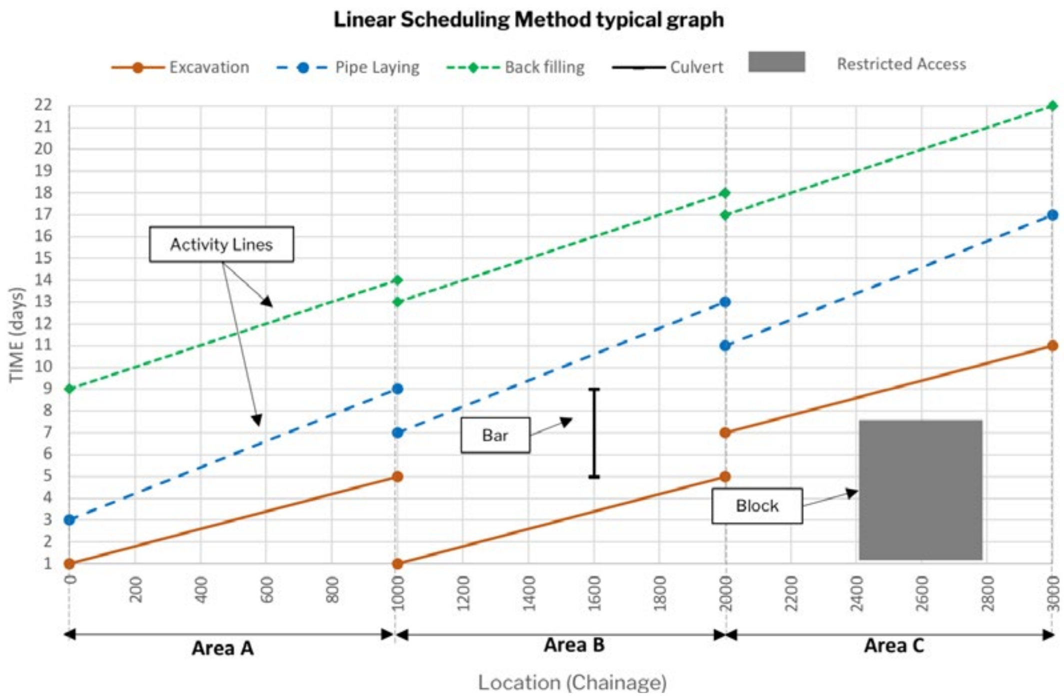

Figure 3 - Example of typical LSM graphical visualisation

[4] There are numerous sophisticated scheduling software tools available for producing graphs for both CPM and LSM. For this paper and for demonstration purposes only, all the CPM graphs have been created in Primavera P6 and all the LSM graphs in Microsoft Office applications, which is a very basic way of creating such scheduling graphs.

APPLICATION OF LSM IN FORENSIC DELAY ANALYSIS

Construction dispute resolution processes often require a retrospective delay analysis to demonstrate the effect of delaying events.[5] The importance of a clear and easily understandable delay analysis presentation, within a construction claim or other dispute resolution proceedings, cannot be overstated.

Retrospective delay analysis methodologies that are based on factual data and linked to contemporaneous as-built project records (for example the "as-planned versus as-built" methodology),[6] provide realistic results when compared to theoretical prospective delay analysis methodologies (for example the "impacted as planned" methodology).[7]

CPM scheduling methods are frequently used in forensic delay analysis. This method has several limitations, particularly when analysing linear projects.[8] CPM graphs do not visually demonstrate changes in productivity rates, for example, caused by potential disruption. Furthermore, CPM graphs do not visually identify the location of activities and/or restrictions that occurred during the project.

LSM scheduling methods used for forensic delay analysis of linear projects can display valuable insight of the actual progress of the works in relation to location. LSM can graphically depict changes in production rates, the interrelationship between resources, locations and durations.

Its visual representations are easy to understand and read, even for those with little to no experience in construction programme management or the project specific details. They are also useful for those who become involved in the project during the latter stages, or where dispute resolution processes introduce new individuals, such as mediators, adjudicators, arbitrators and judges.

Contemporaneous as-built information can clearly and concisely display project history or specific activities/events in relation to the physical conditions in a single graph.

The delay analyst, by reviewing and analysing the LSM graphs, can make considerable observations of the actual progress of the works and structure the delay analysis around the LSM graphs.

Below is a hypothetical case study providing an example demonstrating how the as-built information can be incorporated into LSM graphical tools and what observations/conclusions can be produced by reviewing the LSM graphs for the purposes of forensic delay analysis of linear projects.

CASE STUDY: FORENSIC DELAY ANALYSIS OF A BRIDGE CONSTRUCTION PROJECT

This hypothetical case study assumes a bridge construction of 4km built using the "span-by-span" method.

The main characteristic of the span-by-span methodology is that two consecutive piers must be constructed before the launching girder can step on them to lift and place the pre-cast segments of the bridge platform. As a result, for the bridge platform construction to proceed uninterrupted, the piers must be constructed sequentially away from the start point in the direction of the erection of the bridge platform.

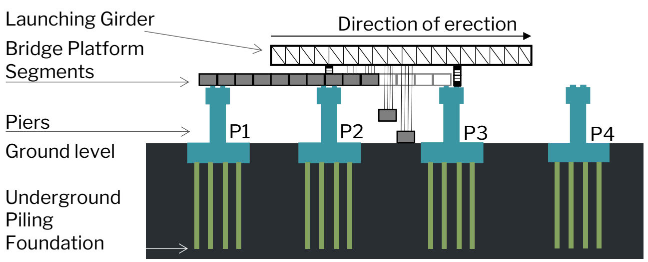

Figure 4 - "Span-by-Span" method of bridge construction

The demonstrative graph in Figure 4 shows that pier No. 1 (P1) is to be constructed first, followed sequentially by P2, P3 and P4. The piers require underground piling foundations, and as a result, piles must be driven before the pier erection could commence.

The planned (and logical) sequence of the main construction activities was as follows:

1. Piling foundation construction (installation of piles), followed by;
2. Piers erection, followed by;
3. Lifting of bridge platform segments.

Figure 4 and Figure 5 below depict the "span-by-span" bridge construction sequence.

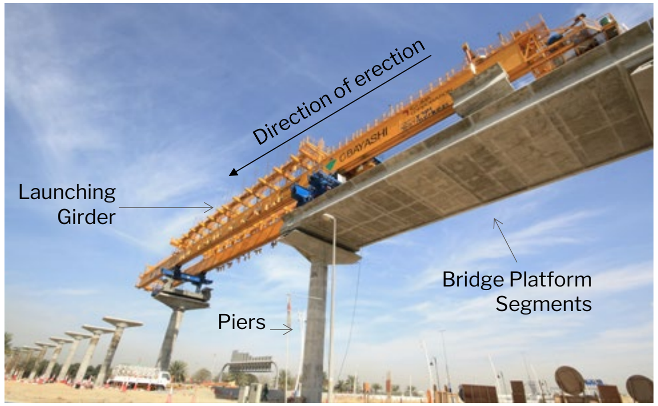

Figure 5 – Example of typical "Span-by-Span" method of bridge construction[9]

[5] Retrospective delay analysis is an analysis performed after the delay events (or the whole project) has completed (i.e. a delay analysis looking backwards to what actually happened)

[6] Defined by the SCL Delay and Disruption Protocol 2nd edition – February 2017, para 11.6(d)

[7] Defined by the SCL Delay and Disruption Protocol 2nd edition – February 2017, para 11.6(a)

[8] Projects which are characterised primarily by their longitudinal spatial nature and/or by their repetitive construction activities.

[9] Source: Dubai metro www.launching-gantryoperator.com/Pages/Dubai%20Metro%20Project%20Photo-Album.htm

Timely completion of the project was reliant upon the efficient and uninterrupted erection of the bridge platform segments from the launching girder. This required work scheduled to ensure that:

1. The actual production rate of the launching girder aligned with the planned production rate; and
2. The erection of the piers followed a sequence and production rate (in the direction of the erection of the bridge platform), to avoid stoppages or disruption to the launching girder operation.

Plotting data for the planned and actual progress of the launching girder operation into the LSM graph highlights periods and locations of (a) slower than planned progress; (b) any work stoppages; and (c) any changes to the planned sequence. These observations can then form the basis of further forensic examination in order to identify the cause and effect of these delay events.

Figure 6 depicts a theoretical LSM example where:

- The dotted black activity line represents the planned progress of the launching girder;
- The straight black activity line represents the actual progress of the launching girder;
- The gradients of the respective activity lines depict the planned and actual productivity rates. The steeper the gradient indicates less work completed in the period, thus a lower rate of productivity;
- The arrows represent the direction of travel of the platform erection and the actual productivity (gradient). Red arrows highlight periods of lower productivity rate than planned;
- Some significant locations are shown in yellow circles, for annotation purposes (i.e. location A, B. C, etc.); and
- The observations arising from the LSM graph are listed in the grey boxes to the right of the graph and are numbered with roman numerals (I, II, III, etc.)

This simple LSM graph with explanatory notes efficiently depicts a comparison of planned vs actual progress of the works and highlights specific periods of delay.

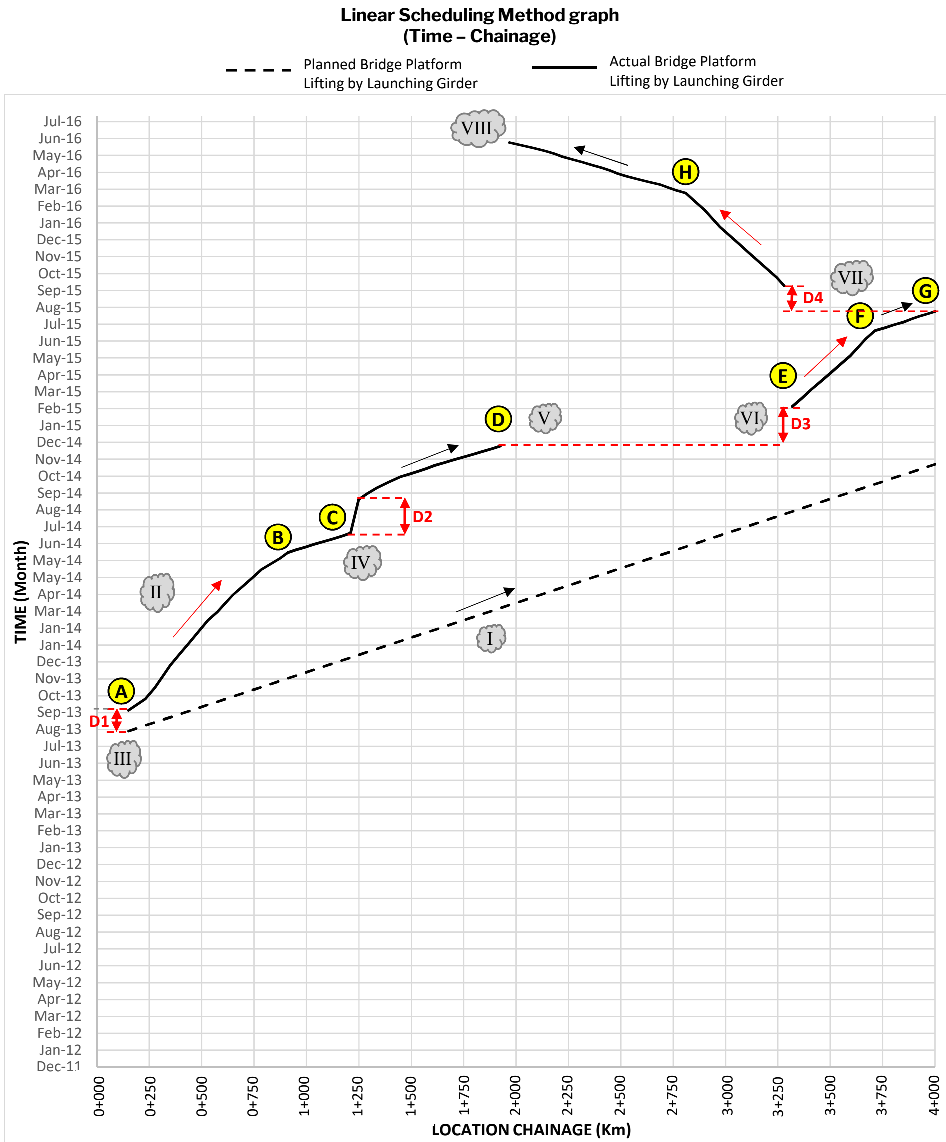

Figure 6 - As-Planned versus As-Built time-chainage graph of Launching Girder operation

Observations from graph

I
Planned sequence (uninterrupted launching girder operation from August 2013 until October 2014, i.e. a planned duration of 15 months)

II
Red arrows highlight the periods of low productivity (i.e. steeper gradient than planned)

III
A delayed commencement of 1 month **(D1)**

IV
Stoppage of the launching girder operation at location C (Ch. 1+250) between June 2014 and August 2014. A delay of around 3 months **(D2)**

V
Stoppage of the launching girder operation at location D (Ch. 1+900)

VI
Contractor either decided or was instructed to divert from the planned sequence and relocate the launching girder to location E (Ch. 3+300). This caused a delay of around 2 months **(D3)**

VII
Once at location G (Ch. 4+000) the launching girder was relocated back to location E (Ch. 3+300) and proceeded to work in the opposite linear direction. This caused a delay of 1 month **(D4)**

VIII
The bridge platform construction completed at location D (Ch. 1+900) in May 2016 (i.e. 19 months later than the planned completion of October 2014)

Further forensic investigations into each delay event enables enhancement of the LSM graph to include additional as-built information that informs detailed conclusions as to specific causes of the delays.

Figure 7 below depicts an enhanced LSM graph where the following enhancements have been added:

1. Actual progress of the piling works (green diamond symbols);
2. Actual progress of the pier construction works for each pier (blue bars);
3. Actual progress of the piling design (yellow bars); and
4. Actual access restrictions to areas of the site (grey blocks).

Activity	**Symbol**
Actual piling construction	
Actual pier construction	
Actual bridge platform segment lifting by Launching Girder	
Actual piling design	
Areas of restricted access	
Planned bridge platform segment lifting by Launching Girder	

Linear Scheduling Method graph
(Time – Chainage)

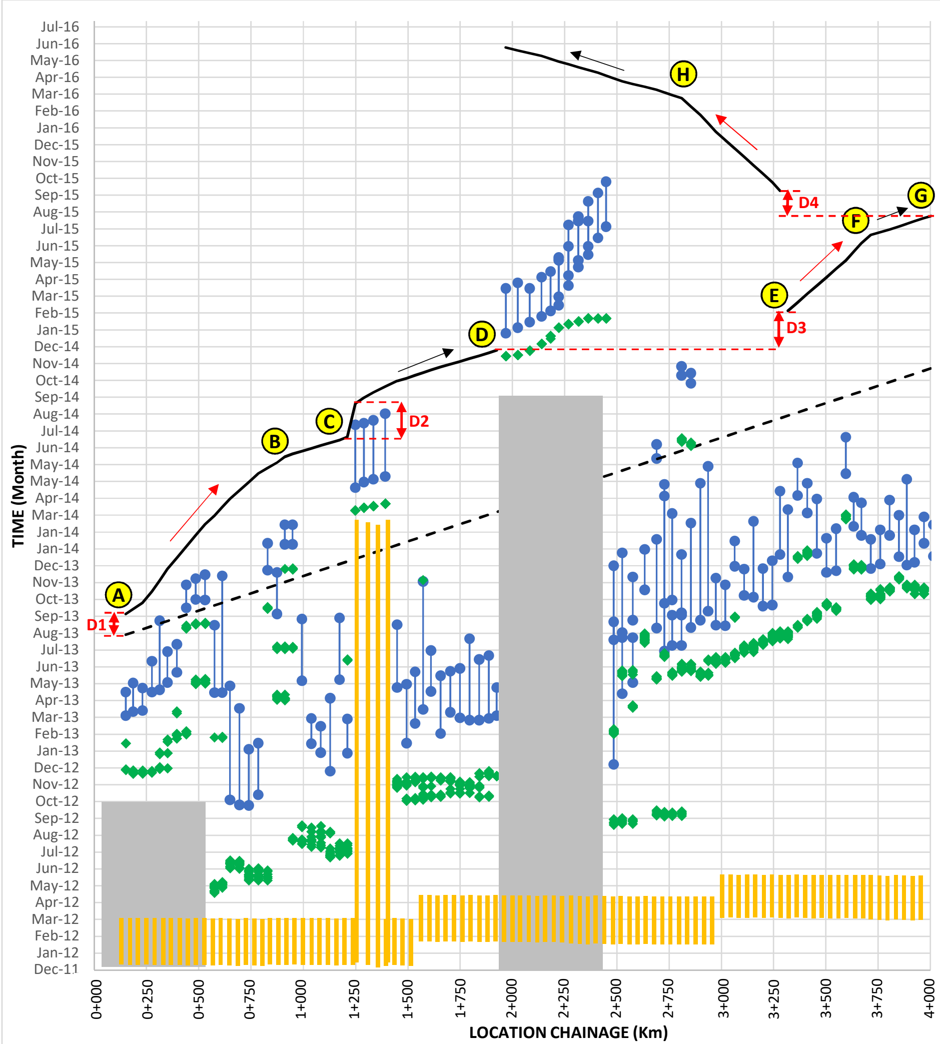

Figure 7 - Detailed LSMgraph (Time – Chainage)

Observations from graph

(D1)
The identification of restricted access at this area (Ch. 0+000 until 0+500) for the first 10 months of the project (between December 2011 until September 2012) highlights a probable cause of delay to the commencement of the launching girder operation.

(D2)
The stoppage at location C (Ch. 1+250) because the following piers (from Ch. 1+250 until Ch. 1+400) required by the programme sequence were not constructed on time. It appears from the significant yellow bars, depicting the actual progress of the design, that the pilling design was significantly delayed. This strongly suggests that design delays may have been the cause of this delay.

(D3)
The stoppage at the location D (Ch. 1+900), and the subsequent relocation of the launching girder to location E, appears to be linked to the long-term restricted access at this area (from the start of the project until August 2014), which resulted in the following piers (from Ch. 1+900 until Ch. 2+450) not to be constructed or available on time.

LSM graphs provide an easy to understand snapshot that convey the actual causes of delays highlighting the periods of low productivity where further disruption analysis can be focussed to identify the specific cause and effects. The disruption analysis helps to demonstrate whether works were disrupted by contract delay events, or, whether the Contractor was not able to perform efficiently.

LSM graphs can be further enhanced with data from contemporaneous records to show relevant impacts upon progress and the rate of productivity. For example, the number of available resources and/or the amount of rain per month can be plotted alongside progress if this is a relevant factor.

Figure 8 below depicts a LSM graph developed to include available resources for each month.

LIMITATIONS OF THE LSM IN FORENSIC DELAY ANALYSIS

LSM graphs used for forensic delay analysis do have limitations.

Similar to all the retrospective delay analysis methods, a typical problem that is often encountered is the availability, format and accuracy of the contemporaneous data records. Creation of LSM graphics requires the delay analyst to import a vast amount of as-built data into the proprietary software application.

A lack of contemporaneous or inappropriately formatted records can be problematic resulting in a time consuming and resource intensive analysis.

LSM for the purposes of forensic delay analysis is a graphical method, that does not rely upon an underlying mathematical model. Various published scientific papers have attempted to define a mathematic model for LSM analyses,[10] but these have not been widely adopted in proprietary software packages. Consequently, the conclusions deriving from LSM graphs, especially regarding the critical/driving activities, are based on the delay analyst's observations, construction knowledge experience and common sense, rather than automated software calculations.

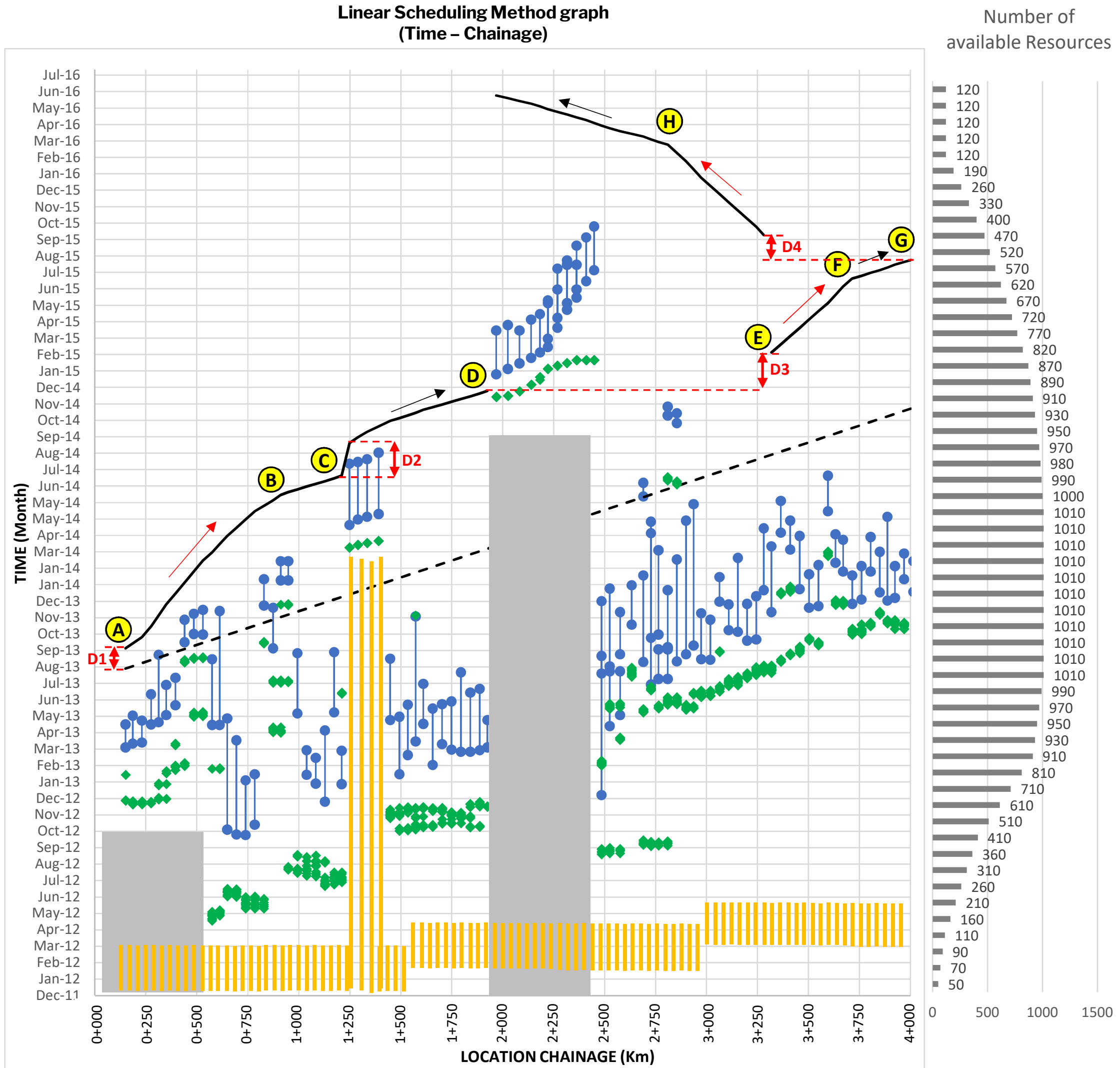

Figure 8 - Detailed LSM graph correlated with number of available resources per month

[10] Some of the more recent scientific papers include: • The Repetitive Scheduling Method (RSM) by Harris and Ioannou (1998); • The Linear Scheduling Model (LSM) by Harmelink and Rowings (1998); • The Critical Path Linear Scheduling Method by Ammar and Elbeltagi (2001); and • The Kallantzis-Lambropoulos Repetitive Project Model (KLRPM) by Kallantzis and Lambropoulos (2004).

CONCLUSION

When applied to linear projects (i.e. highway, pipeline, bridge, railway, tunnelling projects, etc.), LSM can provide a more thorough and informative analysis of the cause and effect of delay events when compared to the CPM method.

As with any delay analysis, the output of LSM is dependent on the quality and accuracy of the raw data available at the input stage and the experience and technical ability of the analysts.

The LSM two-dimensional (2D) graphical representations ("time-chainage graphs") enable a snapshot view and valuable insight comparing, at a glance, planned vs actual performance and productivity, in time and space.

Further forensic analysis can then focus on key events or periods.

LSM graphs are practical, relatively easy to understand, and convey a wide range of information in a format that is easy to assimilate. These are important attributes to consider when supporting claims or opinions before a wider audience in formal dispute resolution proceedings.

ABOUT THE AUTHOR:

Dimitrios Tousiakis is a Director at HKA based in Dubai, UAE. He is a Delay Analyst with over 12 years' experience, both in delay analysis for dispute resolution and directly in the construction industry.

Dimitrios has been appointed as Delay Expert Witness for an ICC Arbitration and has also provided independent expert opinion to contractors and employers on multiple occasions. In the past, he has carried out delay analysis and has assisted appointed delay experts on a range of projects including high-rise buildings, airports, health care, rail and oil & gas.

Dimitrios holds a MSc in Civil Engineering and Business Management by Imperial College London, UK and a BEng in Civil Engineering by Aristotle University of Thessaloniki, Greece (5-years attendance). He is a Chartered Civil Engineer, a member of the Institution of Civil Engineers (ICE) and the Technical Chamber of Greece (TEE).