10 System Dynamics: The next act in Forensic Delay Analysis?

Alexander Voigt, Sam Mattar and Moneer Khalaf – On Disruption and Delay

Towards the end of the 20th Century, the advent of the personal computer popularised the use of software programmes based on Critical Path analysis, to plan and control construction and engineering projects. This popularity eventually led to their use in forensic delay assessments (to settle disputes) – to the point that the Critical Path Method ('CPM') quickly became the norm in this field.[1]

Yet, CPM (like any other analysis method) is not perfect, so it is critical to understand the assumptions upon which it is based, and to be aware of their implications as to where the method will be useful… and where it will not.[2] This article sets out to show how CPM can be of limited use when forensically assessing delay on large, complex and heavily disrupted construction and engineering projects – and it will also show how System Dynamics can be used to overcome these limitations.

Delay claims can have two main objectives, (i) to extend the contractual completion period (to avoid the imposition of liquidated damages or penalties), and (ii) to seek compensation for any additional "time based" costs incurred (called "prolongation costs".) This article focuses on the suitability of delay assessment methods in general, leaving the exploration of the differences between extensions of time and prolongation to a later article in this series.

The various guises of CPM

There is a long list of ways in which CPM can be implemented to forensically assess delay on a project. Thankfully, these ways have already been extensively categorised, described and discussed in the literature[3], so they do not need repeating here. Our present purpose is rather to strip away CPM's technical complexities to focus on its fundamental assumptions, to look at some of the most prominent ways in which CPM is applied, and to examine how it assesses delay, and how its accuracy, reliability and credibility can significantly decline when dealing with large, complex and heavily disrupted projects.

The Critical Path Method

Fundamentally, CPM is based upon the following assumptions:

a) A project can be defined as a series of activities that need to be performed in a certain logical order.

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[1] The field of "forensic" delay analysis includes both (a) prospective assessments (forward-looking, made at the time of a delay event to estimate its likely future impact), and (b) retrospective ones (backward-looking, usually made after project completion to determine the actual delay caused.) While most of this article's insights are generally applicable, its main focus is on retrospective assessments.

[2] For a more extensive discussion on what makes for a valid assessment method, please refer to our earlier article in this series, "04 Proving the Disruption Case: The 'Triad of Proof'". All articles in the series can be found on our website at: www.constructiondynamics.global/on-disruption-and-delay.

[3] See, among others, the "Delay and Disruption Protocol" of the Society of Construction Law, or the "Recommended Practice No. 29R-03, Forensic Schedule Analysis" of AACE International.

b) This order is defined by "precedence relationships", e.g.: "Activity A needs to have started / be completed before activity B can start / be completed".

c) The durations of the activities are determined by a set of self-contained assumptions, including resource-loading and labour productivity rates.

d) There are no interactions between the activities, other than the precedence relationships and (sometimes) the fact that they may share their resources from a finite common pool.[4]

e) When the project is scheduled, there is a string of activities that determine the earliest completion date of the project. This string of activities is called the "Critical Path" ('CP'.) If any single one of these Critical Path activities were delayed, this would cause a delay to the whole project.

CPM was initially developed as a project planning and management tool, to help analysts to schedule activities and allocate resources on projects that were becoming ever more complex. It is in this capacity that the method earned its initial successes, and this eventually (and unavoidably) led to its use in forensic delay analysis (i.e., to provide evidence of delay in legal / contractual disputes.) Yet, it was in this capacity that CPM was quickly confronted with major challenges, because here CPM is used to answer hypothetical questions ("How would the project have performed if the Employer had not done X?", etc.) Perhaps not at all surprisingly, there turned out to be many different ways to deal with these kinds of questions.

To look at how CPM has been used in forensic delay analysis, we will use an extremely simple example. It is true that this will hide most of CPM's actual technical complexities, but this will not hinder our analysis: It is our proposition that the limitations of CPM (when applied to large, complex and heavily disrupted construction and engineering projects) stem from the fundamental assumptions upon which the method is built; the method's detailed technical complexities are immaterial to this discussion, and so they can be safely ignored.

Impacted As-Planned Analysis

The most straightforward, simplistic and easily understood way to apply CPM to assess project delay is the "Impacted As-Planned" method. To explain how it works, we will use an example and assess the delay caused by a single event on a simple project (see Figure 1.) This sample project consists of just six main activities, an initial one ("Substructure"), followed by two separate streams ("Superstructure", "Envelope" and "Finishes" on the one hand, and "Electromechanical" works and "Commissioning and Star-tup" on the other.) Both streams were planned to be completed at the end of week 13.

We know that this project was subjected to one single excusable delaying event[5], which prevented the contractor from starting the commissioning phase (activity #6.) This event lasted two weeks (weeks 10 and 11) – and so the question is: "By how much did this event delay project completion?".

[4] "Resource-loaded" critical path models include this need to share from a common resource pool as another scheduling constraint. Given the additional effort required to set up and update resource-loaded programmes, resource-loaded programmes are not very common.

[5] "Excusable" delays are caused by events or circumstances for which the contract provides the contractor with entitlement to extension of time, or to recover prolongation costs. In laymen's terms: They are employer-responsible, and they are claimable.

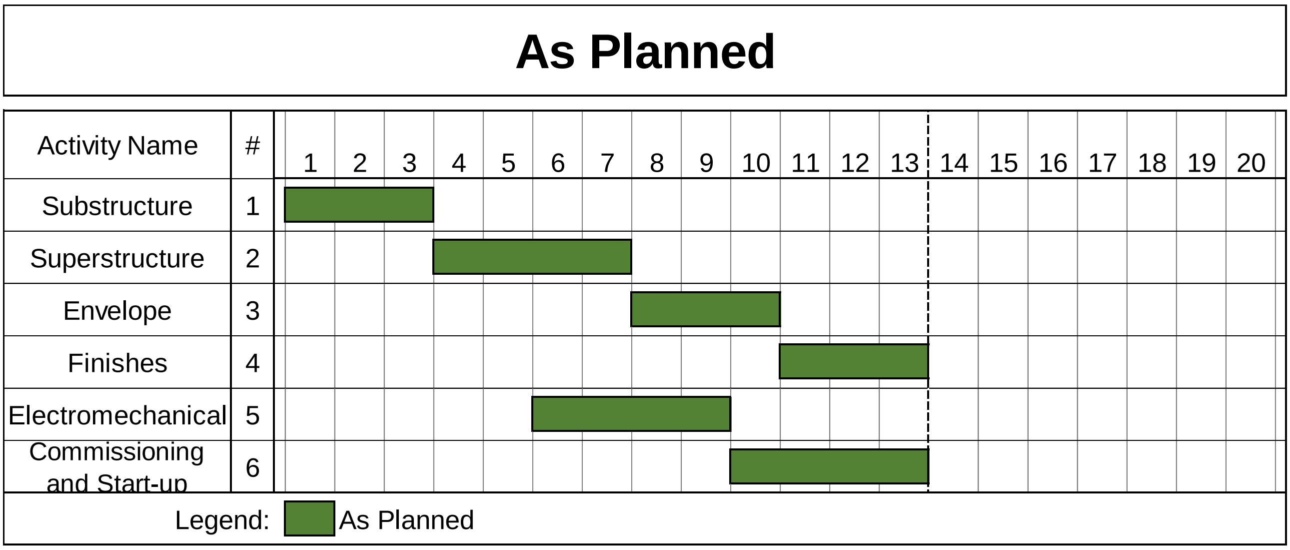


Figure 1: The baseline programme.

Both project activity streams were planned to be completed simultaneously at the end of week 13, it is clear that both streams were on the Critical Path, and a delay to either one would constitute a “critical delay” (i.e., it would impact the completion date of the project.) To determine this mathematically, the ‘Impacted As-Planned’ variant of CPM uses the baseline programme for the project (the “as-planned” schedule), and inserts into it a string of activities (a “network fragment”, or “fragnet”) to represent the delay event (see Figure 2.)

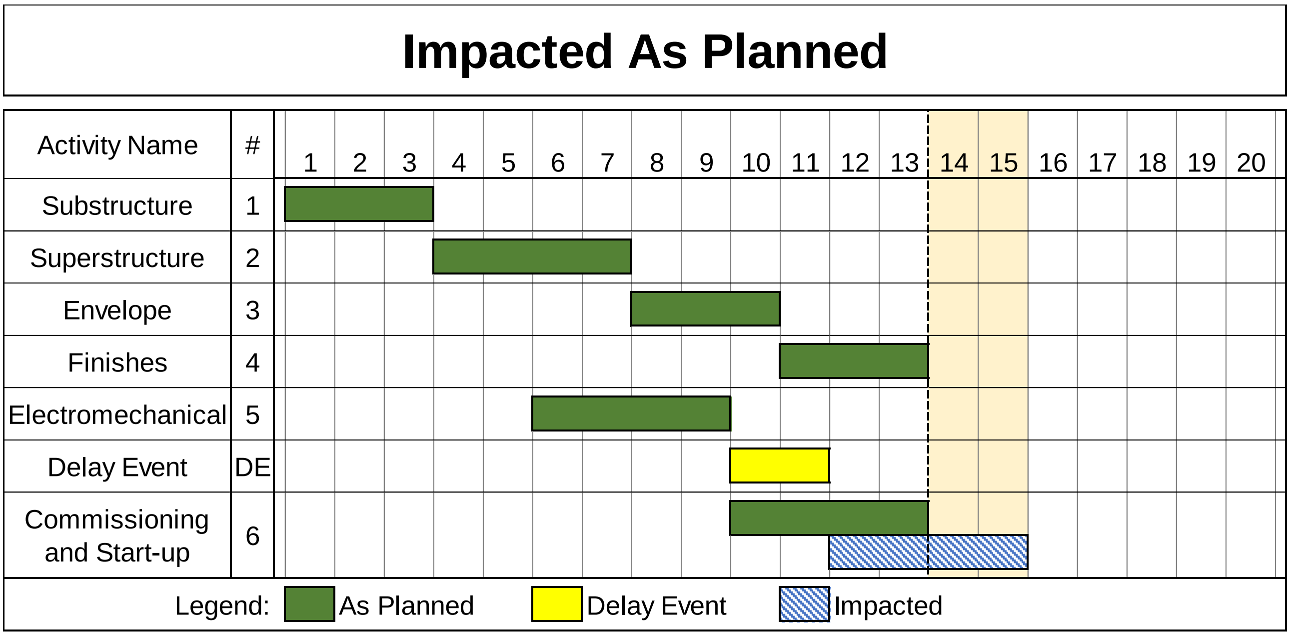


Figure 2: The “Impacted As-Planned method”.

In Figure 2, the green bars represent the activities in the baseline programme. In yellow we represent the ‘fragnet’ (in this case, one single activity) of the two-week delay, and in patterned blue we show the impacted activity. This impacted programme coincides with the baseline up to the time when the delaying event happened, but the start of activity #6 is delayed until the end of said delay event. This pushes the completion date of this last activity on the impacted schedule out by two weeks, as compared to its completion date in the baseline schedule – and this, then, is the project delay caused by the event.

Obviously, the main advantage of this type of CPM is its simplicity: It is always based on the baseline programme, so there is no need to worry about programme updates and actual progress. Thus, the estimation of project delay is straightforward (in principle), and the method can be used both "prospectively" (at the time of the delay), or retrospectively (at the end of the project.)

However, while the key strength of the "Impacted As-Planned" method is its pragmatic simplicity, the method also has at least one critical drawback: It is based on a planned programme developed before the start of the project, and never updated to reflect how said project actually evolved. Since delay claims are supposed to deal with actual damages (in this case, actual delays), this type of CPM has often been challenged when used in legal / arbitration proceedings:

> *"In general, [the 'Impacted As-Planned' method] is thought to be the simplest and least expensive form of delay analysis, but has material limitations [sic], principally because it does not consider actual progress and changes to the original planned intent."*[6]

Time Slice Analysis / Time Impact Analysis

In order to overcome the limitations of the 'Impacted As-Planned' method, variants like 'Time Slice Analysis' or 'Time Impact Analysis' (collectively hereafter referred to as 'TIA') were developed; these insert the event 'fragnet(s)' into updated programmes that reflect the actual state of the Project at the time of the event (or as nearly so as possible.)

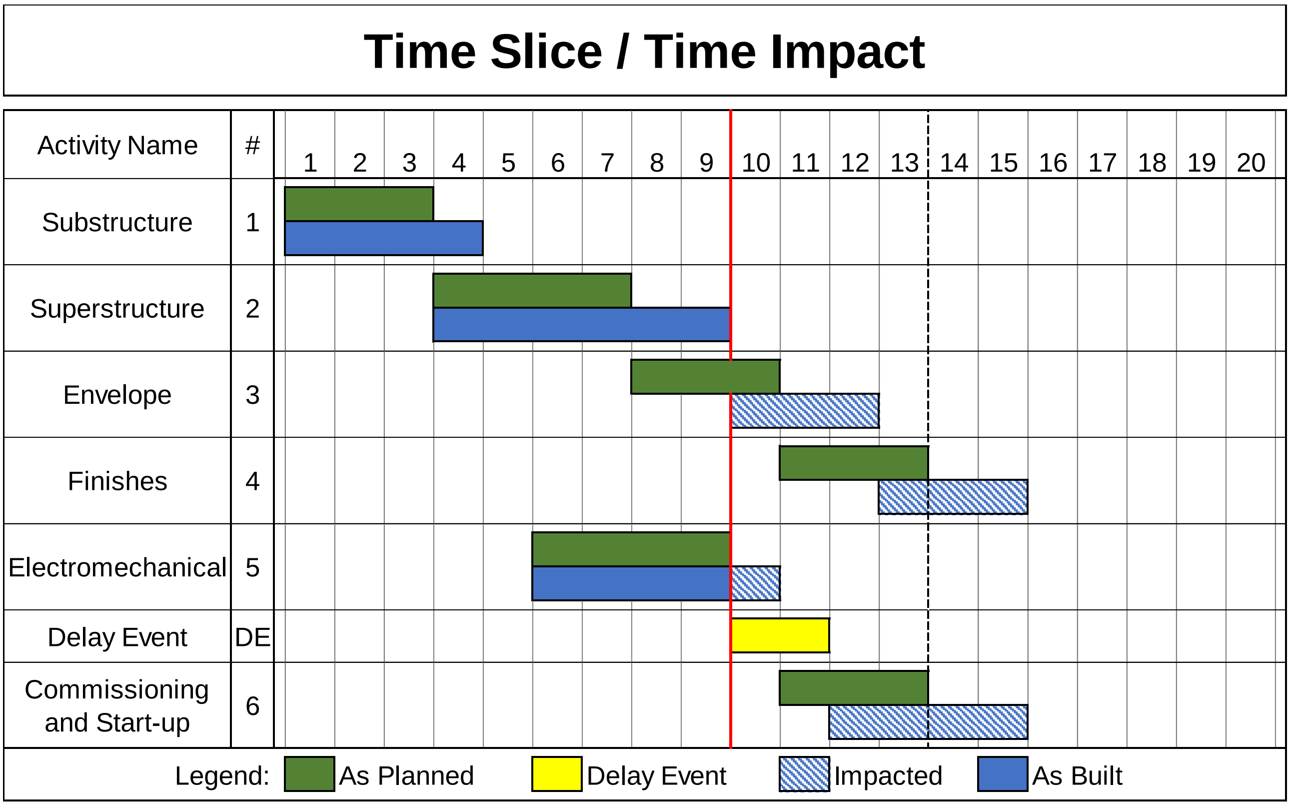


Figure 3: The "Time Slice Analysis" / "Time Impact Analysis" methods.

[6] Society of Construction Law (2017), "Delay and Disruption Protocol", 2nd Edition, p.35.

To understand the implication of this refinement, let us turn again to our simple example: Figure 3 shows how by the end of week 9, the project had already strayed significantly from the initial plan. Structural works (activities #1 and #2) had accrued a delay of two weeks, and Electromechanical works (activity #5) were also running late… so much so that an updated schedule produced at the end of week 9 showed that the "Electromechanical" works would still require one more week to finish. The delay event only affected "Commissioning and Start-up"; since the start of this activity had already been rescheduled by one week in the updated programme, the delay event only delayed it by one additional week.

But, what was the impact of the delay event on the project's overall schedule? Well, as it turns out, the answer is: It had none. Figure 3 shows how both activity streams were expected to be completed 2 weeks late; the second stream would have finished earlier if the delaying event had not occurred (1 week), but the expected completion date of the first stream (unaffected by the event) would not have changed at all – and, therefore, the completion date of the overall project would not have been affected, either.[7]

This simple example shows how important it can be to use accurate and contemporaneously recorded progress data within updated programmes to assess delay. As the project is executed, the programme is updated based on actual recorded progress data, reflecting the cumulative impact of all the changes that happened on it. Very often, these re-schedulings can accumulate and cause the Critical Path to shift, leading to significant differences in the result of project delay assessments than would have been obtained using the original baseline programme. So, while an "Impacted As-Planned" assessment may be the only available option on projects that (for whatever reason) were unable to maintain an updated programme, if updated programmes are available then using TIA will deliver more accurate (and thus more defensible) results.

To recap: TIA is the most complex type of CPM, and up until recently it appeared to be the preferred one by courts, tribunals and experts. In the words of D'Onofrio *et al*.:[8]

> *"The only method that follows all [the required] guidelines is the properly adjusted time impact analysis."*

Assessing actual delay: As-Planned vs. As-Built

But, having arrived at this point, there is another issue to consider:

> *"Any delay analysis must take into account what actually happened on the project. […] Schedule delay analysis methods that ignore the as-built schedule have repeatedly been rejected."*[9]

Why is this the case? An authoritative voice often cited in this regard is the Honourable Justice (as he then was) Hamblen in *Adyard Abu Dhabi v SD Marine Services [2011]*:

[7] Of course, real engineering and construction projects are usually impacted by more than one delay event. In this case, the events would first need to be grouped chronologically, and each group would be assessed based on the updated programme that was closest to the dates of the events.

[8] D'Onofrio, R. M., Meagher, A. L. (2013), "What is a Schedule Good For? A Study of Issues Posed by Schedule son Complex Projects", Construction Lawyer, Winter 2013, p. 11.

[9] Ibid, p. 6.

> *"The [event] relied on must actually prevent the contractor from carrying out the works in the contract period or, in other words, must cause some actual delay."*[10]

In other words, assessments need to be able to prove that an actual delay occurred, not just a "theoretical" one. This represents a problem for TIA because the delays calculated by this variant are still (in essence) theoretical ones: The programmes used by them still assume that, following the delay event, the project will be completed in strict adherence to all precedence requirements – something which is, more often than not, unrealistic.

Our simple project also reacted in this way. Figure 4 shows how the project was actually completed, and compares it to the initial baseline programme. And indeed, activities #2 and #6 were started before their corresponding precedent activities were fully completed, most probably in an attempt to mitigate mounting project delays. Bottom line, in our simple example the TIA would have overestimated the impact caused by our delay event.

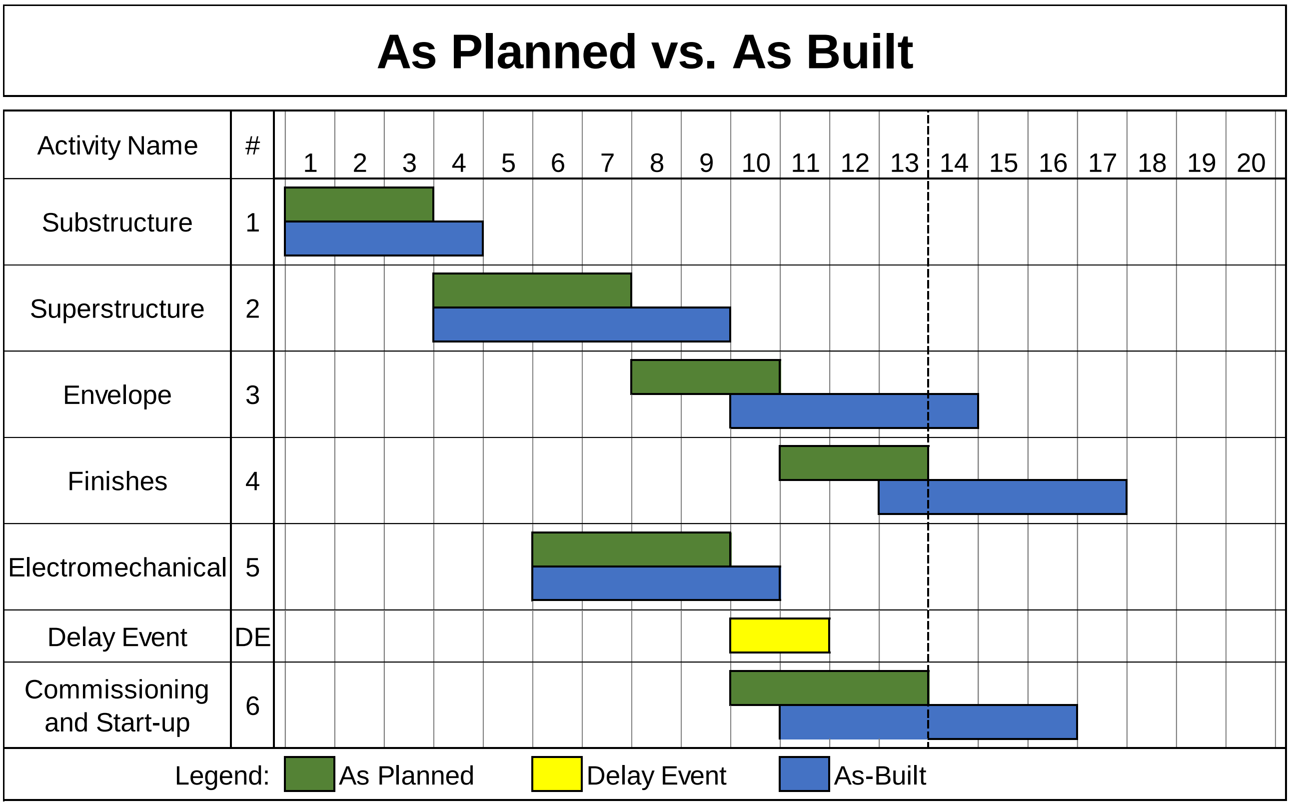


Figure 4: The "As-Planned vs. As-Built" method.

However, Figure 4 also shows how the actual durations of many activities exceeded their planned durations, which caused shifts in the critical path and gave rise to delays that were not accounted for by TIA. To make sure that analyses captured the <u>total</u> and <u>actual</u> delays caused to a project, a new CPM variant has been gaining favour recently: the "As-Planned vs. As-Built" method. While previous CPM variants (like TIA) started by defining certain delay events, and then attempted to ascertain their impact on the project ("event-first"

[10] *Adyard Abu Dhabi v SD Marine Services* [2011] EWHC 848 (Comm), [2011] BLR 384, 136 Con LR, (2011) 27 Const LJ 594, note 16, para [282].

methods), the "As-Planned vs. As-Built" method works the other way around (it is an "effect-first" method): It compares the project's plan to what actually happened, and then looks for the facts (events) that can help the analysts to reconcile the differences with the project's original plan.

Returning to our simple example, an "As-Planned vs. As-Built" assessment would have easily determined that the delay event did not end up on the project's Critical Path, and that therefore it could not have been responsible for any of the project's delay.

And yet… clearly this cannot be the whole story? What about all those activities that took so much longer to complete? Indeed, this is one of the strengths of the "As-Planned vs. As-Built" method. By looking at the actual delays and requiring that they are explained, it unearths events that other CPM approaches would have missed simply because (by mistake or design) they were not on the list of events to be considered. But sadly, this is when we realise that we are no longer standing on solid ground with our delay analysis, because longer activity durations and task overlaps are significant changes to the planned intent, and so are a symptom of an altogether different phenomenon: disruption.

The interplay of delay and disruption

How does disruption affect project delay?

We have described the nature of delay and disruption in previous articles in this series[11], explaining how they are different yet related concepts. Here we focus on the interplay between delay and disruption, and who better to introduce the topic than the Society of Construction Law?

> *"Delay and disruption are inherently interrelated. A loss of productivity (i.e. disruption) can lead to delay and, if the impacted activities are on the critical path, that can be critical delay."*[12]

Looking into it more specifically, there are several ways in which disruption can impact project delay:

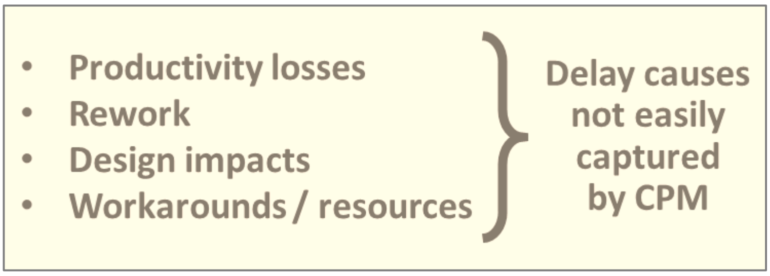


Figure 4: Types of disruptive impacts that delay construction.

a) Productivity losses

In our simple example, if the project was efficiently staffed then the additional duration of the activities can only be ascribed to lower productivity – which means disruption. Therefore, a disruption assessment will be

[11]For additional information, please see our previous article in this series "02 A Causal Framework for Disruption and Delay: Loopy, Not Straight" and "03 Disruption: Such an Elusive, Tricky Animal…".

[12]Society of Construction Law, "Delay and Disruption Protocol" (Second Edition, 2017), p. 10.

required to determine why/how productivity was affected, and therefore, which party was responsible (the contractor, or the employer.)

Generalised productivity losses have a direct impact on the duration of a project. If we assume that (a) the original planned estimate was accurate, (b) no changes are made to the project's sequencing and (c) all activities are efficiently staffed, then the duration of a project is inversely proportional to the manpower's productivity – e.g., a halving of productivity will lead to a doubling of the project's duration.

Having analysed a variety of projects over the last two decades, it is our experience that large, complex construction and engineering projects can suffer productivity losses that can exceed 50%. Therefore, the delaying impact of productivity losses cannot be dismissed.

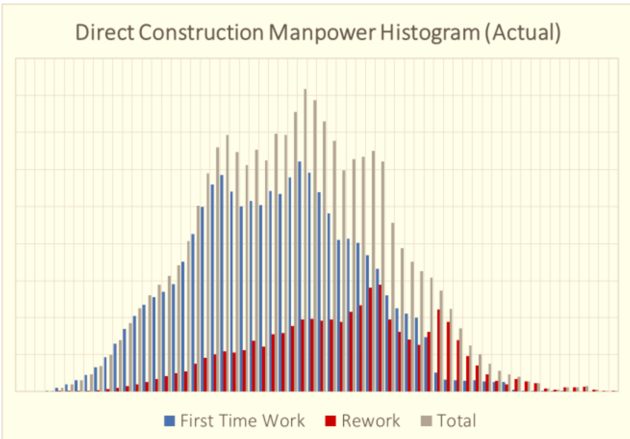
On a sample of recent construction projects in the MENA region assessed by the authors, overall productivity losses ranged from 8% to 52%, being on average 29%.

b) Rework

Rework is a fact of life on construction and engineering projects: Nobody is perfect, some mistakes are always made, and when a project is subjected to changes and other disruptive events, rework can grow exponentially.

A large fraction of the rework required on a project is often not found until the latter stages of construction (during "snagging" / "punch-listing" of the works), and this (late) rework often is a substantial contributing factor of delay to the project's completion date.

On the same sample of recent construction projects, direct construction hours spent on rework ranged from 10% to 30% of the total.



A disproportionate fraction of the rework hours was spent near project completion, as was the case in the (redacted but real) case shown above.

c) Design changes

There are many ways in which the design process in a project can be disrupted: Design specifications may be incorrect or incomplete, changes may be introduced ("officially", or surreptitiously via comments on reviewed drawings), the review and approval of the drawings may be delayed, etc.

These events (particularly when happening late) often have a direct impact on construction work, requiring that certain activities be re-sequenced, delayed, reworked, or a combination thereof. However, most project programmes do not include the design (or shop drawing) phase, and in these cases CPM delay analysis cannot capture the delaying impact of the interplay between design, engineering and construction.

Furthermore, the cumulative impact of the disruption also needs to be considered. As the changes heap up, with the occurrence of further delay and disruption to already delayed and disrupted design activities, progress in the design phase is slowed down, and this inevitably ends up by severely impacting construction. On tightly scheduled projects, this necessarily means that construction will be delayed as well.

These kinds of impacts could only be properly captured by CPM if the design phase was included in the baseline programme… but even this may not be enough. The programme would also have to be constantly updated to reflect any and all design changes, and this can prove to be near-impossible: On many complex projects, a significant fraction of the design changes may not be officially considered as such, but instead are disguised as rework ("instructed" via comments on reviewed drawings, for example.) The sheer volume and frequency of these changes, coupled with the fact that the changes are "hidden" as rework, makes it impossible for CPM to account for them in any reasonable shape or form.

Last but not least, it should not be forgotten that changes in design usually also impact the procurement process, with parts (or even whole systems) being re-specified, re-manufactured, and/or re-delivered. It can easily take months for the whole procurement process to play out (from issuing an order to receiving the material on site), and this can significantly exacerbate delays caused by design changes (especially when made during the later stages of the project.)

d) Workarounds and impacts on resources

If the above were not enough, when projects are severely delayed, acceleration happens: Measures are undertaken to make up for the delay. For example, when facing delays project management often responds by adding more manpower, so that more activities can be worked in parallel (as shown in our simple example, see Figure 4.) This shortens the Critical Path, but it violates the project's planned resourcing and sequencing, thus resulting in disruption. With neither the time nor the resources to properly plan and manage the evolving situation, these kinds of deviations from the initial plan typically result in programmes becoming ever more separated from the reality of the project.

Equally, project management may react in a combination of ways to mitigate the impact of even more complex events, like (for example) late inspections. When inspections are sufficiently delayed on a project, supervisors will start to take matters into their own hands to mitigate delay and/or disruption, redirecting waiting crews to other available activities (and even to out-of-sequence ones.) Or, they may ignore some inspection holds and continue to work at their own risk (and consequently face increased levels of rework later on.)

It should be noted that these workarounds are the cumulative result of many small, lower-level decisions. Given their small magnitude and the large number of these decisions, project control analysts usually lack the data, resources and/or time to reflect the impacts of these workarounds on their projects' programmes. Thus, workarounds are hardly ever properly reflected in project CPM analyses.

Proving delay in the face of disruption

As we described in detail in an earlier article in this series[13], the effectiveness of any delay or disruption assessment method depends on its ability to satisfy the requirements set out in the 'Triad of Proof'. In a nutshell, this means that in order to establish entitlement to delay, and assessment method needs to:

a) Establish a causal link between the events and their ultimate impact;

b) Accurately assess the actual damage inflicted by the events; and

c) Clearly isolate the damage caused by relevant events from overruns caused by other reasons.

So, now that we have reviewed the kinds of disruptive impacts that may have caused some of our project's delay, can CPM establish what caused these impacts? Furthermore, can CPM also quantify the magnitude of the delays caused by each event, or keep track of how the disruptive impacts rippled through the project, all of them overlapping and compounding each other (as is generally the case with disruption)? Can CPM account for rework when it hardly ever captures it in its programmes (either planned or actual)? Can CPM establish that a construction activity was delayed by the late arrival of a procured materials, which was caused by the late issuance of design drawings, which in turn was caused by the design team's inability to keep up with their schedule because they had been bombarded by changes?

There really is no need to keep going. On large, complex and heavily disrupted projects, CPM cannot overcome the limitations that we have described in this article, and therefore, it simply cannot defensibly prove entitlement to delay caused by disruption.

Currently: Add a little disruption to your delay analysis

In recent years, the construction and engineering industries have begun to take notice of the shortcomings of CPM, and have become aware of the role that disruption can play in project delay. For example, the second edition of the SCL's "Delay and Disruption Protocol" (published in 2017) suggests that:

> *"[…] the Contractor may rely upon a disruption analysis to support a critical delay claim in addition to is delay analysis."*[14]

Further, AACEI RP No. 29R-03 echoes this statement, suggesting that taking the delaying impacts of disruption into account could be accomplished by translating productivity losses into additional durations for individually affected activities[15].

So, clearly both the SCL and the AACEI acknowledge that disruption may affect a project's completion date, and they suggest that separate disruption assessments can be used to factor in the delays caused by productivity losses into delay analyses otherwise still based on the Critical Path Method.

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[13] Please refer to our earlier article in this series "04 Proving the Disruption Case: The 'Triad of Proof'".

[14] Society of Construction Law (2017), "Delay and Disruption Protocol", 2nd Edition, p.35.

[15] AACE International (2011), "Recommended Practice No. 29R-03, Forensic Schedule Analysis", p.35.

However, while this may be a step in the right direction, we would like to respectively propose that it does not go nearly far enough.

Proposed: Two sides of the same coin

The approach suggested above simply cannot work on large, complex and heavily disrupted projects. CPM may attempt to show the sequence in which activities were (and/or will be) executed, but this is nothing but an illusion, a chimera. CPM-based project management systems are simply not (yet) capable of effectively tracking the thousands of little factors (changes, productivity losses, workarounds, rework, unplanned delays etc.) that affect a project's programme on a daily basis, nor can they reliably link these factors to specific actions by the employer, either.

The Society of Construction Law already points in this direction when it states that disruption and delay are two sides of the same coin:

> *"Delay and disruption are inherently interrelated. A loss of productivity (i.e. disruption) can lead to delay and [...] delay can lead to disruption."*[16]

When projects are heavily disrupted, using a disruption assessment to simply "enhance" a conventional CPM delay analysis cannot yield a defensible result – the answer, rather, lies in a more integrated approach. Any attempt to separate the two will lead the analyst to ignore causal connections that exist in the real project being analysed, and this will translate into analysis results that will be divorced from reality. Since delay assessments are supposed to determine the magnitude of the actual impacts on the project's schedule, it is clear that separating disruption from delay will lead to less defensible claims.

The only accurate way of assessing disruption and delay on large, complex and heavily disrupted projects, is to do so jointly.

System Dynamics: Assessing disruption AND delay

There currently only exists one method that can assess disruption and delay jointly: System Dynamics.

System Dynamics simulation models explicitly capture the productivity losses arising from disruptive events (as well as the rework caused by them), they account for all interdependencies between design, procurement and construction, and they simulate the workarounds and changes in resources also driven by disruptive events. In other words: System Dynamics overcomes all the limitations of CPM, and is thus the only method to reliably prove entitlement in complex delay claims.

System Dynamics is the only method that can reliably capture the full disruptive and delaying impacts on large and complex projects.

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[16] Society of Construction Law (2017), "Delay and Disruption Protocol", 2nd Edition, p.10.

We have already described how System Dynamics is used to assess disruption and delay in earlier articles in this series[17], so here we will only recap a few key points:

- System Dynamics uses computer models to simulate the project.
- SD simulation models are carefully calibrated so that they are able to accurately reproduce the project's actual performance ('As Built' simulation.)
- To do this, SD simulation models include the impact of all disruptive and delaying events, irrespective of the party responsible for them (the employer or the contractor.)
- To assess employer-responsible disruption and delay, employer-responsible events are removed from the model – this way models produces a second scenario, the 'But For' simulation.
- The differences between the 'As Built' and the 'But For' scenarios (regarding resources employed and completion dates achieved) form the basis for disruption and delay claims.

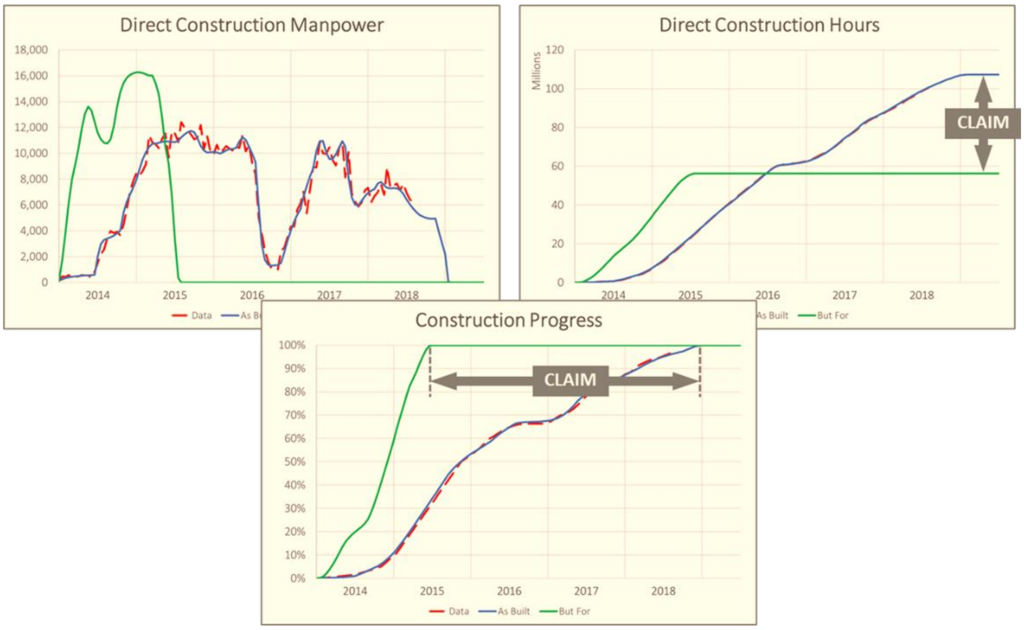

Figure 5: 'As Built' vs. 'But For' scenarios on a recently completed assessment (disguised.)

System Dynamics has been used to successfully analyse disruption and delay on complex projects since 1976. While companies, courts and tribunals have used and accepted SD for decades, it took the construction and engineering mainstream forty years to "officially" recognise SD's suitability to assess disruption[18]. This recognition should now be extended to the assessment of delay as well.

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[17] For more information on how System Dynamics assesses disruption and delay, please see our previous article in this series: "05 Applying System Dynamics to Assess Disruption and Delay: The 'D3A' Approach".

[18] The bellwether event that unofficially marked a fuller recognition of System Dynamics by the construction industry is generally felt to be the method's inclusion into the Society of Construction Law's 2nd edition of its "Delay and Disruption Protocol", in 2017. The milestone events that mark the acceptance of System Dynamics by the construction and engineering industries will be the focus of an upcoming article in this series.

System Dynamics and the Critical Path

There is a key trade-off that is made by System Dynamics in order to assess project performance: Its simulation models forego a detailed representation of the project at the activity level, in order to accurately and effectively capture the disruptive dynamics that (as we just saw) drive project performance and delay.

But if we are talking about a "trade-off", that means that there must be a downside to it as well, and indeed, there is one. By not representing the project at the activity level, it is impossible for SD to distinguish between individual activities, and thus it cannot distinguish which activities are on the Critical Path.

Naturally, the immediate reaction of anyone having used CPM to plan, manage and/or assess complex projects would be to assume that if a method cannot account for the Critical Path, then it cannot be used to assess delay. Yet, System Dynamics has been used in this capacity for over forty years, so it must be possible.

So, how does System Dynamics do it?

While it is true that SD simulation models do not represent individual activities and their sequencing explicitly, it cannot be said that they altogether ignore the concept of the Critical Path, either. SD models do capture the constraints imposed by the project's sequencing, as well as the effects that actions violating these constraints have on project performance:

1. SD models break down projects into major work phases, and capture the constraints binding these together. For example:
    - Progress on downstream work phases cannot start until sufficient progress is made upstream.
    - When the above-mentioned constraint is broken, productivity and work quality on downstream work phases suffer, and manpower is also affected (in extreme cases, work is stopped altogether.)
    - Progress in downstream work phases speeds up the discovery of rework in upstream work phases.
2. Within a work phase, SD simulation models are fed data regarding activity sequencing <u>in aggregate form</u>, using it to define the constraints that limit the amount of work that can be done in parallel at any point in time (based on how much work has already been completed within that phase.) This aggregate data on activity sequencing thus enables the simulation model to estimate the duration of each work phase's critical path at each point in time.

Using System Dynamics AND Critical Path Methods

While System Dynamics certainly can produce more accurate delay assessments on heavily disrupted projects, this does not mean that CPM should no longer be used on them. CPM will always be an indispensable tool to properly plan and execute engineering and construction projects – in these fields SD may support key strategic decisions (providing more accurate forward-looking insight into the likely future evolution of the project), but the basis for day-to-day management needs to be CPM-based: Gangs will always still need to be told where to go and what to do, and this requires planning and management tools that work at this level of detail.

But even beyond this, CPM should still remain a very useful resource in forensic delay analysis of complex projects, as it provides critical inputs that cannot be supplied by SD:

- System Dynamics simulation models require aggregate information about the sequencing of the project's activities – CPM-based tools will be needed to provide the necessary raw data.

- A comparison of the differences between SD and CPM analyses will remain a valuable cross-check of the validity of the assumptions made by both methods, and thus lead to more reliable output.
- In certain extreme cases, key events may cause delaying impacts that are disproportionate to their size (bottlenecks…) A CPM analysis of these events will provide SD with the information it will need to properly capture these extraordinary impacts in its simulations.

Conclusions

While disruption and delay may be two different phenomena, they are still two sides of the same coin, with one rarely occurring without the other. Distinguishing between the two may make sense from a legal perspective (to distinguish the different types of damages that a project may suffer) but it does not make sense to analyse separately that which is so closely intertwined.

On large, complex projects that are heavily disrupted, CPM will remain a critical resource to plan and manage the works, but when it comes to forensically analysing their delays, what is needed is an approach that connect both disruption and delay – distinct, but interrelated. System Dynamics is the only method that can accurately and defensible do so.

Of course, some may object to the use of System Dynamics to perform forensic delay analyses, on the basis that SD is not yet "officially" recognised as a delay assessment method for the construction industry (for example, by the SCL or by AACEI.) We can only hope that this recognition will arrive soon, but in the meantime, it should be pointed out that there is generally no rule (nor are there any contractual clauses) that can prevent contractors and employers from using any reliable method chosen by them to prove their entitlement to Extensions of Time and/or prolongation costs, be it in arbitration or in litigation.[19]

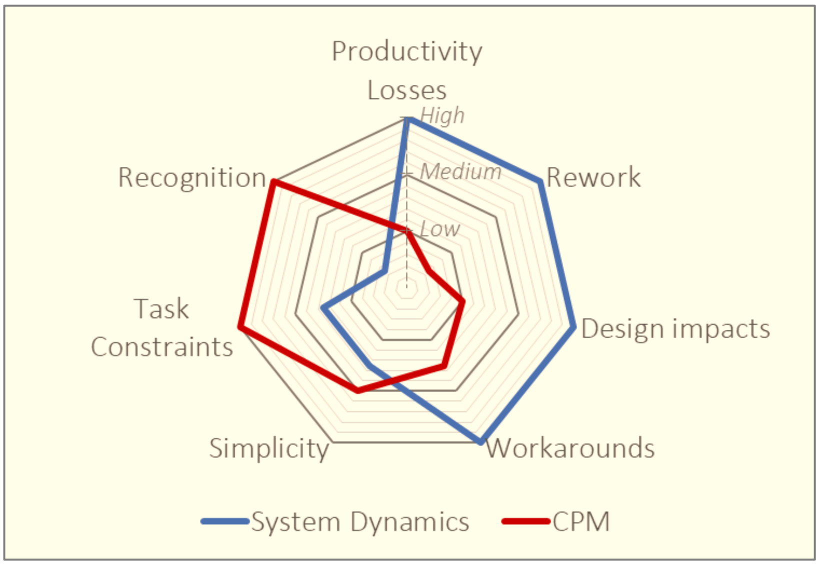

Figure 6: Comparative effectiveness of CPM and System Dynamics as forensic delay analysis methods on large, heavily disrupted projects.

[19]The topic of the "admissibility" of SD as a forensic delay analysis method will be addressed in more detail in a later article in this series.

Postscript

To avoid excessive complexity, this article has not addressed the fact that delay analyses can be done prospectively (at the time when a delay event happens, or its impact is felt), or retrospectively (looking back, usually after project completion.) This article was written bearing in mind mostly retrospective analyses, (a) because these are more often used in arbitration and/or litigation, and (b) because disruption is rarely detected and quantified contemporaneously, making a retrospective analysis the only viable approach when dealing with heavily disrupted projects.

Nonetheless, it should be noted that System Dynamics can be used proactively / prospectively, and this issue will be discussed in more depth in a later article in this series.

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