Construction
Dynamics
Solutions

Dynamic Disruption and Delay Analysis (D3A)

Data Requirements

Types of data needed, where to find them, and what to watch out for.

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Table of Contents

0. Data philosophy

The preparation and analysis of claims in construction projects can be complex and demanding; especially when it comes to data and information, both of which are critical to proving causation and calculating damages defensibly.

The purpose of this guide is to set forth the basic information and data requirements in performing a successful disruption analysis in support of a claim.

Before we start discussing about data, though, it will be helpful to set it in context: we must first appreciate what disruption claims are about, and define a data philosophy consistent with that understanding.

0.1. Disruption and efficiency losses

Disruption is caused by changes: changes lead to losses in efficiency, these efficiency losses drive the need to spend additional resources to complete the same scope of work… and this is what we call disruption. Typically, the main resource considered in disruption claims is manpower, although other types of resources can also be considered (like equipment, for example.)

Efficiency losses are never recorded contemporaneously, since measuring efficiency *as it occurs* would take up vast amounts of resources that would lead to skyrocketing project costs. So, basically, efficiency losses are always estimated after the fact – and there are many different methods to do so. In this guide we will focus on the System Dynamics method.

0.2. System Dynamics ('SD'), efficiency and data

0.2.1. Disruption, efficiency, productivity and rework

Disruption arises on a project when more resources are required to complete a certain amount of scope than should have been necessary – or, in other words, when the resources employed (mainly labour) suffer a loss in efficiency. The two potential causes for a loss in efficiency are:

a) A loss of productivity

b) Additional rework.

Productivity "…refers to quantities produced per employee hour of effort…" and, or alternatively (and equivalently) as "…the ratio of output to input…"[1,2,3].

This definition of productivity assumes that the all the output being achieved by the resources involved is actually counted as such… but this is not always the case – in fact, it is hardly ever the case! The reason is that on any project, some amount of work is always accepted (or at least recorded) as being correct and complete, when in fact it is not so: there are always some bits that eventually turn out to be incomplete or incorrect, and thus will need to be reworked. Thus, **rework** is another source for efficiency losses, because it consumes resources and yet does not produce any measurable output[4].

[1] AACE International: Recommended Practice No. 25R-03 Estimating Lost Labor Productivity in Construction Claims; TCM Framework: 6.4 – Forensic Performance Assessment

[2] Kavanaugh, T.C., Muller, F. & O'Brien, J.J., Construction Management: A Professional Approach, McGraw-Hill Book Company, New York, 1978, p. 387

[3] Finke, Michael R., Claims for Construction Productivity Losses, 26 Pub. Contr. L.J. 311, page 312

[4] Work being re-done will have generally already been accounted for as "done" when first completed, and this accounting is usually not rectified when the need for reworking it becomes evident. Thus, rework cannot get credited for any additional output.

The definitions for productivity and rework may be simple enough, but these variables are deceptively difficult to measure: productivity is almost impossible to track while a project is ongoing, because of the massive effort that would be required to do so. Tracking rework is somewhat easier (and it is indeed sometimes done), but generally speaking there are no contemporaneous project records on rework, either[5] (other than end-of-project 'snag lists'.)

0.2.2. Data used to estimate efficiency

What the above means in practical terms is the following: since efficiency cannot be measured contemporaneously, it can only be estimated after the fact, based on contemporaneous data which does exist. To determine what these pieces of data should be, we need to look back at the definition of efficiency:

$$\text{Efficiency} = \text{Output} / \text{Input} \quad [1]$$

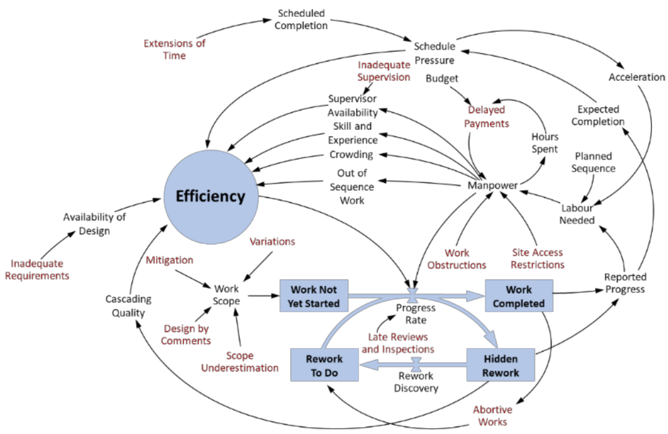
In construction, the output of the project is measured by its progress, and the main resource employed is labour. Therefore, the equation above can be rewritten as follows:

$$\text{Efficiency} = \text{Progress} / \text{Manpower} \quad [2]$$

0.2.3. System Dynamics

The Society of Construction Law's 'Protocol for Delay and Disruption' describes 'System Dynamics' as: *"[…] a computer simulation approach using specialist software to produce a model of the disrupted project. That model replicates the complex network of relationships and interactions that influence labour productivity and rework including the various stages of the project (design, approvals, procurement or manufacturing, installation, construction, commissioning and taking over), the different parts of the works, workflows and project participants, and the direct effects of the claim events."*[6]

What is relevant about this definition is that it shows how SD is all about understanding impacts on productivity and rework – and productivity losses and rework (jointly called 'efficiency losses') are precisely the two sources for disruption.



Causal framework that forms the basis for a typical SD model of a project.

[5] This statement refers to construction. In design and engineering, rework is often tracked via drawing submittal logs (which track resubmittals.)

[6] Society of Construction Law, Delay and Disruption Protocol (2nd Edition), Feb. 2017, ISBN 978-0-9543831-2-1, page 48 (Guidance Part B, paragraph 18.16.e)

In a nutshell, System Dynamics simulation estimates the varying levels of efficiency achieved over the lifetime of a project by looking at the patterns in the data for **manpower used** and for **progress achieved**, and then applying Equation [2]. It then uses a mathematical causal framework to simulate the project, attempting to replicate the levels of efficiency just determined – but without making direct use of the data mentioned above.

The 'mathematical causal framework' used is a computer-based simulation model: its equations capture how project characteristics, management decisions and resulting performance all influence each other, and also how different types of changes impact this interplay.

0.3. Major data focus areas

Because of the distinctive nature of SD disruption analyses, the data used by the methodology is also somewhat different from what is used by other methodologies. In order to help guide the efforts of data gathering teams, we want to explicitly define here the major areas of focus of any data gathering effort for a disruption analysis using SD:

- When looking at the historical record, teams will focus mainly on data for **progress** and for **manpower** (for the reasons described above.)
- In order to be able to explain the variations in efficiency implied in the records for progress and manpower, we will also need to look for **data describing the changes** that were introduced to the project.

1. How is data used in a simulation model?

1.1. Data types

As previously described, the purpose of a dynamic disruption analysis is to determine the magnitude and timing of the efficiency losses suffered. The simulation models used in our analyses require three very different types of data:

a) <u>Project characteristics</u>. This data describes the basic characteristics of the project as understood at the time of the contract: its scope, budgets, schedules, staffing plans, etc. See section 2.2.8.

b) <u>Calibration time series</u>[7,8]. This data is used to determine the magnitude of the efficiency losses suffered on the project. As previously explained, this requires the historical records of actual project performance (resources used and progress achieved.) See section 2.

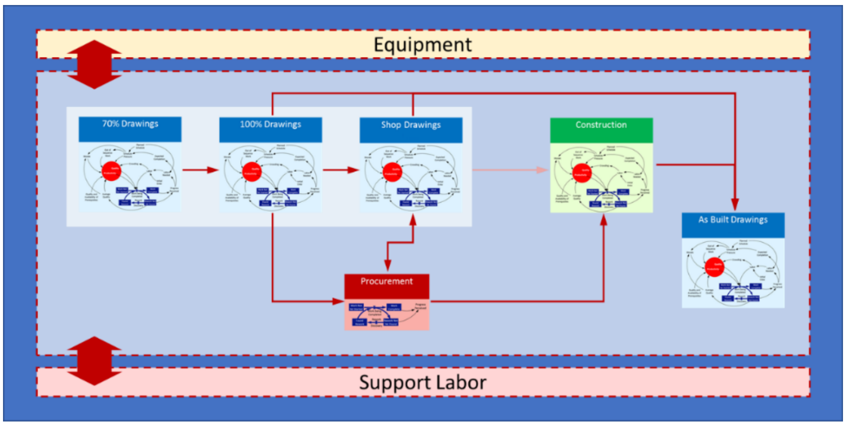
c) <u>Direct impacts of disruptive events</u>. This data describes the magnitude and timing of the changes introduced over the lifetime of the project. The changes will be described by how they directly impacted the project. See section 4.

1.2. Level of detail

D3A analyses project performance from a top-down perspective: the units of analysis are the 'work phases', groups of tasks or activities of a similar nature, executed by the same group of people. This means that the analysis will report average results for each work phase, and will not be able to make any further distinctions within each one. And, of course, this also means that the <u>data used in the analysis will need to distinguish separately the different work phases</u>.

The actual number of work phases to be used on any given analysis will depend on its purpose (interim claim, expert opinion on an international arbitration, etc…), on time and resources, and on the availability of the data. Since it will not be immediately obvious what data is available where, a preliminary work phase breakdown will be defined at the start of the project, but it may be revised later on. For this reason, <u>data should always be gathered at the highest level of detail available</u>[9]: it is much easier to combine elements later on, than it is to introduce additional distinctions.

Below is shown a typical work phase breakdown that could be used in a model geared towards arbitration:



[7] Time series are typically also referred to as 'histograms'.

[8] We are using the name 'calibration time series' because most often calibration data will consist of time series. However, it should be noted that sometimes this data may also simply consist of single parameters.

[9] Within reason, of course.

1.3. Data needs to cover the whole project

As we just explained, SD simulation models reproduce how project characteristics, management decisions and project performance all interact. One major implication of this apparently simple sentence is that <u>SD models need to simulate the whole project</u>: all aspects of a project influence each other, and the consequences of events or decisions ripple through time and through all areas of the project. Therefore:

- The data needs to cover the totality of the works – critically, this means that the data needs to <u>include all subcontractors</u>.
- The data needs to <u>cover the complete duration of the project</u>, from the signing of the contract: even if an analysis is supposed to only cover later periods of a project, the conditions at the start of this period would still have been shaped by whatever happened before.
- The data needs to <u>account for all the major changes suffered by the project</u> – irrespective of the party that introduced them. All changes are disruptive, and thus the actual performance of the project cannot be explained without taking all changes into account.

1.4. Disruption and delay

One major aspect of the causal framework used by SD is the link between delay and disruption: they are tightly interlinked, and one cannot be understood without the other (disruption leads to additional delays, and delays lead to additional disruption!)

For this reason:

- <u>Programmes and schedules are relevant data</u> to be gathered for SD analyses. Some of this data will be useful background/reference information that will guide the SD modelling effort, and some may be directly used in the model (as described in this document.)
- SD simulation models inform not only about the disruption suffered on a project, but also about its delays. SD works at a higher level of aggregation (less detail) than do most commonly used delay analysis methods – for this reason, SD has so far proven to be more difficult to explain and accept for schedule analyses, and thus is not yet used very often for this purpose.

  However, <u>SD is actually the only method that can capture the totality of the delay suffered on a project</u>, since it is the only method that can account for the delay caused by disruption (productivity losses and rework.)

1.5. Data and estimation

This document describes where the data required for D3A can typically be found. However, please bear in mind that all projects are different, and that therefore a minimum amount of creativity may be needed.

<u>To the extent possible, analysis data should be based on project data</u>. In other words, the figures used in the analysis should be based on figures contained in contemporaneous project reports, contractor or owner databases, contractual documents, etc.

However, SD models will need inputs that will typically not be immediately found among existing project data – this means that <u>some amount of data will necessarily need to be estimated during the analysis process</u>. Typically, the need for estimation applies to data concerning project characteristics and disruptive events, and this will be described in detail in the following sections (as and when applicable.)

2. Calibration time series

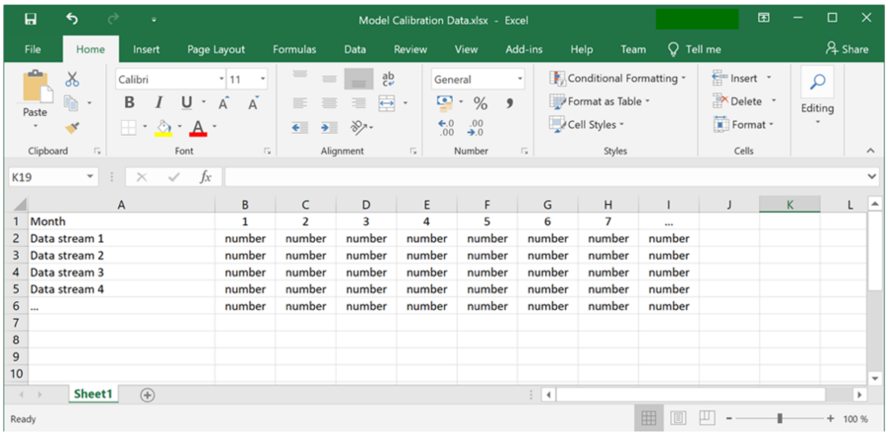
A System Dynamics simulation model aims at reproducing the actual performance of the project is analyses. In order to achieve this, the analysis obviously needs to gather the data that describes such performance. As described in section 0.2, this means mainly data about resources used and progress achieved.

2.1. Preliminary considerations about time series data

2.1.1. Formatting

The eventual purpose of the data described in this guide is to be usable in a mathematical, computer-based simulation models. This means that all the data and information to be used need to be in numerical form.

In order for the model to be able to read data, it eventually needs to be produced in the following format:



Sample time series data input sheet.

2.1.2. Timing

Regarding timing, we need to distinguish between two main types of time series[10]:

a) Data describing the situation of the project at the end of each time period – for example, hours spent or cumulative progress achieved.

b) Data for the average value of a variable during each time period – for example, monthly manpower or monthly rate of progress.

The simulation model handles both types of data in different ways, so it is critical that data input spreadsheets like the one shown above clearly separate data of both types.

[10] The SD model simulates the project over time, and conceptually it treats time as a continuous flow rather than as a discrete number of steps.

2.1.3. Consistency between resources and outputs

As previously explained, the data for both resources (labour) and progress is used to estimate historical efficiency levels on the project. In order for this estimation to be accurate, the data for both resources and progress needs to refer to the same activities:

a) Resource data (labour) needs to include all those resources that generated the work represented in the progress data – and only those resources.

b) Progress / scope data should reflect the full amount of work (output) produced by the resources captured in the resource data (generally labour.) Progress /scope data may not capture all the work accomplished, but at least it needs to be representative of the total amount of work done.

Note that the data for progress also needs to be consistent with that for scope (see sections 3.1, 3.2, 3.3 and 3.4), since progress needs to be measured against a defined work scope.

2.1.4. Consistency over time (time-series only)

The units of work being counted need to be homogeneous, i.e., the effort required to complete a given number of work products may not vary significantly over time. If it does, then the manner in which the average effort varies over time must be documented.

If two or more types of work products are produced in the same phase, and they require significantly different amounts of effort, then the progress data will need to combine the different types of work products by weighting them with the average effort required to produce each.

2.2. Calibration data required

2.2.1. Design[11] manpower and hours spent

The record of average manpower and total hours spent each month.

Source: Time sheets, payroll data.

Hours spent per designer per unit of time

When there exists only data for either manpower or hours spent, but not both, we will require the number of basic hours spent per person per unit of time (typically a month.)

If there is no usable data on hours spent but there is at least a partial record of such, this might be used to extrapolate the hours spent per person to the whole project. If this were deemed not to be accurate/representative enough, the parameter might be extracted from payroll data or directly estimated by people familiar with the project.

2.2.2. Overtime

Whenever possible, and especially on projects where the use of overtime changed over time, teams should gather the overall number of hours of overtime per month (or alternatively the average % of overtime used each month.)

Source: Time sheets, payroll data, manager estimates.

[11] The term 'design' heretofore will refer to any possible design or engineering phase, including concept, preliminary and final design, and the production of shop drawings and/or as-built drawings.

2.2.3. Design progress

There are two main potential data sources:

a) % progress achieved, as reported in (monthly) progress reports.

b) Drawing submittal logs. These logs should specify at least the following fields:

   i. Drawing number
   ii. Drawing title
   iii. Revision number
   iv. Submittal / batch number (if drawings are submitted in batches)
   v. Submittal date
   vi. Review date (when approved / rejected / …)
   vii. Review code (approved, approved with comments, rejected, cancelled…)

If none of the above are available, design progress can also be estimated by Project managers. In this case, it can be helpful to break down the design scope of each phase into smaller blocks, using major milestones as reference points.

Source: Weekly or monthly reports, drawing submittal logs / databases

2.2.4. Construction manpower and hours spent

The record of average manpower and total hours spent each month, differentiating direct vs. indirect labour:

a) Direct labour – generally defined as labour groups executing the works and achieving progress against the defined scope of work.

b) Indirect labour – generally defined as labour groups executing support tasks, mid-level management, etc…

Source: Daily, weekly or monthly reports, payroll data.

Hours spent per person per unit of time

When there exists only data for either manpower or hours spent, but not both, we will require the number of basic hours spent per person per unit of time (typically a month.)

If there is no complete data set on hours spent but there is at least a partial record, this might be used to extrapolate the hours spent per person to the whole project. If this were deemed not to be accurate/representative enough, the parameter might be extracted from payroll data or directly estimated by people familiar with the project.

Source: Daily, weekly or monthly reports, payroll data, manager estimates.

2.2.5. Construction progress

The preferred way to measure construction progress (and thus also construction scope, since these two variables need to share the same units of measurement) is via budgeted person-hours completed monthly, data that is usually available from Earned Value systems. This specifically measures progress in terms of the effort that executed works should require in an undisrupted environment – thus, it is the perfect unit of measurement to lead to sensible efficiency estimates (via the use of equation [2], as defined in section 0.2.)

Sometimes progress is also measured in terms of "% schedule complete". This way to measure progress is less useful since, strictly speaking, it does not directly measure output achieved. However, if no better data exists, "% schedule complete" can be used (the SD model can be adapted to track it.)

Source: Weekly or monthly reports, project management information systems. Interim payment certificates may also be used, especially if they break out labour, equipment and materials.

2.2.6. Start and completion dates

We will want to capture all possible information about the evolution of the planned start and completion dates for all the different work phases (for both design and construction.) This means capturing not only changes to contractual dates, but also the evolution of internal schedules ('expected' completion dates, etc…)

Source: Project programmes / schedules.

2.2.7. Equipment used

SD simulation models primarily simulate project manpower, and resulting project performance. However, if desired then models can also simulate the equipment used on the Project. To do so, the model will distinguish between 'fixed' equipment (types of equipment whose numbers do not vary based on the manpower employed at each point in time), and 'variable' (types of equipment whose numbers do vary mainly based on the manpower employed at each point in time.)

The data for equipment used on the project needs to distinguish between 'fixed' and 'variable' equipment; main types of data used are equipment count (average number of units used every month), and equipment value (same as previous, but weighted by the value of the equipment used.)

Source: Daily, weekly or monthly reports.

2.2.8. Procurement progress

Progress in procurement is usually tracked in several different ways:

a) Purchase order (PO), fabrication and delivery logs, containing the following fields:

   i. PO ID
   ii. PO title
   iii. PO revision number
   iv. PO submittal date
   v. PO review date (when approved / rejected / …)
   vi. PO review code (approved, approved with comments, rejected, cancelled…)
   vii. Value of material
   viii. Fabrication start date
   ix. Fabrication completion date
   x. Date when material is delivered to site

b) Material approval logs, containing the following fields:

   i. Material sheet ID
   ii. Material sheet title
   iii. Material sheet revision

iv. Material sheet submittal date
v. Material sheet submittal approval/rejection date
vi. Material sheet submittal status (approved, rejected…)

Note that it is important to also gather the prerequisites required for each type of document (What types of other documents needed to be issued first? Did these have to be approved first? If so, by whom?)

Source: Procurement logs.

2.2.9. Inspections

Inspection logs should specify at least the following fields:

a) ID
b) Scope of work inspected
c) Date of inspection request
d) Date when inspection started
e) Date when inspection concluded (if different from start date)
f) Status of inspection (approved, rejected…)

Source: Inspection logs.

2.2.10. Testing

Testing activities are relevant when simulating testing and commissioning phases.

Testing logs should specify at least the following fields:

a) Test ID
b) Test name
c) Date of test
d) Status of test (passed, failed…)

Source: Testing logs.

2.2.11. Project productivity reports

This document is based upon the assumption that productivity will not have been measured on the project, because most often this is the case. However, for completeness' sake it should be stated that, in the rare instance when productivity reports for the project are available (for whatever work phase), they should obviously be gathered and they will be immensely valuable to the disruption analysis.

Source: Project productivity reports.

3. Project Characteristics

3.1. Initially planned design scope

Scope needs to be defined in the same units of measurement as progress. Thus, initial scope can be defined as 100% (if design progress is defined in terms of % progress achieved), or in terms of the number of drawings expected to be completed (if progress is measured by the numbers of submitted and approve drawings.)

Note that planning figures should only be used if they were considered to be reliable **at the time**. See also section 4.3.1 for initial scope underestimation.

Source: Logical value (100%), or initial plans or estimates.

3.2. Final design scope

Final scope figures should equal the initial scope plus the sum of all scope changes caused by disruptive events. However, please note that this figure still needs to be validated for consistency:

a) If scope is defined in %, the final scope figure should be independently estimated by Project managers.
b) If scope is defined in terms of the number of drawings, then the final scope should obviously coincide with the total number of drawings submitted over the lifetime of the Project[12].

Any inconsistencies detected during this checking process will need to be resolved before any of the data involved in the check can be used in the simulation model.

Source: Project manager informed estimate (% increase over initial plan) or drawing submittal logs.

3.3. Initially planned construction scope

Scope needs to be defined in the same units of measurement as progress. Thus, it can be defined as 100% (if construction progress is defined in terms of % progress achieved), or in terms of budgeted hours (if progress is measured by the numbers of budgeted hours completed.) Please note that the latter is preferred (see also section 2.2.5.)

Note that planning figures should only be used if they were considered to be reliable **at the time**. See also section 4.3.1 for initial scope underestimation.

Source: Logical value (100%), or initial plans or estimates.

3.4. Final construction scope

Final scope figures should equal the initial scope plus the sum of all scope changes caused by disruptive events. However, please note that this figure still needs to be validated for consistency:

c) If scope is defined in %, the final scope figure should be independently estimated by Project managers.
d) If scope is defined in terms of actual data (like budgeted hours), then the final scope should obviously coincide with the sum of scope changes that occurred over the lifetime of the Project.

[12] Note that we are counting drawings, not submittals. Thus, three submittals of the same drawing should count as one, not as three.

Any inconsistencies detected during this checking process will need to be resolved before any of the data involved in the check can be used in the simulation model.

Source: Project manager informed estimate (% increase over initial plan), project re-measurement figures.

3.5. Initially planned start and completion dates

Start and completion dates for all project work phases, as set at the start of the Project.

Source: Contract, Correspondence, inference from initially planned manpower or progress charts.

3.5.1. Initial duration of Critical Path / Initial schedule "float"

While SD models do not simulate the tasks that form the Critical Path, they still simulate how the length of the Critical Path evolves over the duration of the Project. If schedule float is used in planning the Project, the initially planned duration of a work phase will exceed the initial duration of its Critical Path, and both are data needed for the analysis.

Source: Contract documents, initial plans and estimates.

3.6. Initially planned budgets

The number of person-hours initially believed to be required to complete the work in a work phase.

Note that budget refers to the hours actually expected to be spent, not to the scope of work to be executed – it is important not to confuse both variables: scope measures work, the budget is a planning figure referring to the resources expected to be needed to complete the work.

Even when measuring scope in terms of budgeted person-hours, the scope and budget of a work phase still don't need to match since both may be based on different assumptions: the budget may include a buffer for rework, the scope of work may have been determined using pre-established planned productivities, etc…

Source: Initial plans and estimates.

3.7. Labour turnover statistics

The average number of people leaving the project because of their own decisions over a defined period of time, as compared to the average size of the workforce[13].

People leave projects for many reasons, many not having anything to do with the needs of the project: attrition. When people leave for their own reasons they have to be replaced, and often their replacements will not be as skilled or have as much experience. For these reasons, it is worthwhile to keep track of this phenomenon.

Source: Project manager reports, manager estimates.

[13] Note that, when the time period is less than the duration of the project, then this data item will no longer be a parameter but it will have become a time series. This will transform this data into calibration data, and all the considerations stated in section 2 will apply.

3.8. Planned manpower pattern / Work parallelism

The simulation model needs to know how much work can be done in parallel over the duration of each work phase: whether manpower should be frontloaded, whether there are any particular work sequence bottlenecks, etc.

Ideally, this information will be deduced from the resource-loaded initial plan for the Project, by following this two-step process:

a) First, mark how much planned manpower could work in parallel at given progress points (0%, 10%, 20%, etc.)

b) Second, normalize these figures by dividing by dividing them by the largest one (so all figures will range from 0 to 1.)

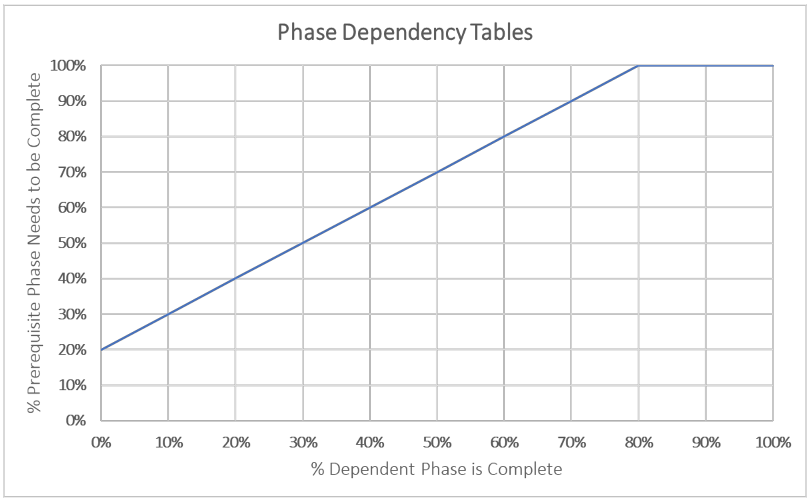
For the purposes of a dynamic disruption analysis, the resource-loading should be made so that all non-critical activities are executed as soon as possible. (However, if time permits it would also be helpful to repeat the exercise when back-loading non-critical tasks.)

If planning data did not exist, then the information would need to be estimated by Project managers in structured workshops or interviews.

Source: Contract Documents, Schedule estimates, or Project planning systems (Resource Loaded Programme.)

3.9. Phase dependency data

The dependency between two work phases is captured in X-Y tables. These tables show how much progress need to be achieved by the prerequisite phase (vertical axis) in order for the dependent phase to be able to make unhindered progress – for any given degree of completion of this dependent phase (horizontal axis.)



Typical work phase dependency tables.

These curves are used in the following way:

- In the space above the curve, the dependent work phase has all the prerequisites that it needs, and this it can proceed without incurring any productivity or rework losses.
- In the space under the curve, the dependent work phase will incur productivity and rework losses due to missing prerequisites – the further away we are from the curve, the more severe these losses will be, until efficiency in the dependent phase reaches zero (no further work can be accomplished[14].)

In the example shown above, when the follow-on phase is about 50% complete it needs its prerequisite phase to have completed at least 70% so that follow-on work can continue unimpeded.

The two main potential sources for this information are planning systems (like a P6 system, for example), and estimation workshops with relevant Project managers or planners.

3.9.1. Phase dependency data derived from planning systems

Phase dependency relationships can be derived from the resource-loaded schedules of the initial Project plan, by plotting against each other the planned progress curves of the prerequisite and the dependent work phases.

Note that it is recommended that this type of data also always be supported by direct estimates from Project managers (see section 3.9.2.)

Source: Project planning systems (Resource Loaded Programmes.)

3.9.2. Phase dependency data estimated via workshops

If there is no hard data on phase dependency, or if that data is not conclusive enough, the phase dependency relationships can also be defined via workshop (or interviews) with project managers.

The best way to estimate the dependency relationships is to start by defining the start and end points for each: how many prerequisites (how much upstream work) is needed so that the dependent phase can start working, and how much is needed to complete all of the dependent work?

Once the end points have been established, we use well-known milestones to define as many additional points as possible.

Each estimate for each data point should be supported by as much corroborative evidence as possible, based on project plans, facts and the managers' experience.

Not that **each dependency relationship should be estimated independently** by as many experts as possible. If the resulting estimates differ, a workshop among the experts should be arranged in order to reach a consensus.

Source: Project managers or planners.

[14] Often, dependency tables will include a second curve, showing where efficiency in the dependent phase would reach zero.

4. Direct Impacts of Disruptive Events

4.1. Disruptive events and Direct Operational Impacts (DOIs)

SD simulation models are able to account for most types of disruptive events, by capturing the direct operational impacts (DOIs) that they have on projects. In other words: the simulation models contain the data for the direct impacts of the disruptive events… and the models' equations then generate the indirect impacts (disruption.)

The following graph shows a list of the most commonly found types of disruptive events, and the types of DOIs typically associated with them. These events and their impacts are described in detail in sections 4.3 and 4.4.

Disruptive Events (DEs)	Scope Added	Fraction of Design Uncertain	Direct Productivity Impact	Forced Rework / Obsolescence	Unjustified Rejections	Excessive Reapprovals	Additional Drawings	Excessive Review Time	Staffing Constraints	Work on Hold	Excessive Inspection Time	Ratio of Supervision to Direct Labour	Scope Deleted
	Direct Operational Impacts (DOIs)												
Initial Scope Underestimation	✓	✓											
Incomplete/ Incorrect Specifications/ Requirements	✓	✓	✓										
Design Changes	✓	✓		✓									
Design by Proxy (Comments, RFIs,…)	✓	✓		✓	✓	✓							
Fragmented reviews					✓	✓							
Additional drawing requirements							✓						
Delayed Reviews								✓					
Site Access Restrictions			✓						✓	✓			
Holidays									✓				
Weather Conditions			✓						✓				
Work Obstructions									✓	✓			
Delayed Work Inspections											✓		
Lack of Adequate Supervision												✓	
Scope Deletions													✓

Typical Direct Operational Impacts of typical disruptive events.

4.2. Preliminary considerations about data on disruptive events

4.2.1. Data sources and types of disruption analyses

Because SD deals with a wider range and breadth of types of disruptive events than other methods do, then by necessity SD has to deal with a significant amount of data that is required… but that is not yet available. Thus, a significant amount of data has to be generated for the analysis, and depending on the purpose of the analysis this data generation effort can be more or less onerous.

For example, let us look at a disruptive event that involves a major design change, which resulted in a significant increase in design scope. To support an interim claim, it might be sufficient to use scope growth estimates from expert project managers, but for arbitration proceedings it would be better to look for 'hard' data (like number of additional drawings.)

4.2.2. Comprehensiveness regarding applicable work phases

Very often, disruptive events will affect more than one phase of work – it is important to remember this when gathering the data about the events.

For example: when dealing with a design change, we may focus on how this impacted the design work on the Project… forgetting how the same change would also have increased the scope of procurement and construction work phases!

4.2.3. Data should account for each individual disruptive event – whenever possible

Ideally, the data should separately capture the impact of each disruptive event, since this may be of interest to the parties of the claim, or (when applicable) to the tribunals and/or courts.

However, we should note that this is not always possible, due to limitations regarding the available data: for example, design changes may have been issued via variation orders that estimated the construction budget (and thus scope), but which may be silent on the design scope affected by each.

When itemized data is not available by event, it is critical to at least capture the total impact of all events (total magnitude, and estimated rough timing.)

For example, on a remeasured project the data may not have captured the construction scope added by each design change, but it will at least have established the final constructed scope. This will be usable, as long as Project managers are able to estimate the rough timing for when the scope was added.

4.3. Major types of disruptive events

This section describes the nature and characteristics of the more commonly found types of disruptive events, and enumerates the DOIs typically associated with them. Since different types of events can sometimes have the same kind of direct impact on a project, in order to prevent repetitions, the DOIs will be described separately in the next section.

Please note that this section does not pretend to be exhaustive: it covers the situations commonly found on construction projects, but it does not cover any possible type of event, nor does it cover all possible DOIs for the types of events that are covered.

Further, please note that, except where explicitly noted, disruptive events can have been caused either by the Contractor or by the Employer. The party responsible for each particular event will need to be determined event by event (and this process should always be supported by legal/contractual experts.)

4.3.1. Initial scope underestimation

Prior to the start of the works, the Contractor will necessarily have only an imperfect knowledge about the scope of the work to be done (even the best planning is never perfect.) Depending on several factors (extent of pre-contract planning and review, tender duration, market conditions at time of bid, soundness of Project design and/or specifications…), the difference between the actual and the expected initial scope of the works can be significant, and if so, it needs to be considered as a disruptive event.

Typical DOI(s): Scope added (see section 4.4.1), and potentially also design uncertainty (see section 4.4.2.)

4.3.2. Incomplete/incorrect contract specifications or requirements

If the design information supplied by the Employer[15] is deficient (incomplete, incorrect and/or uncoordinated), the Contractor will have to do additional work beyond what he expected while planning the project.

Typical DOI(s): Scope added (see section 4.4.1), and potentially also design uncertainty (see section 4.4.2.) Depending on the data available and on the structure of the simulation model, the scope addition caused by this type of event can also (instead) be expressed as a direct productivity loss (see section 4.4.3.)

4.3.3. Additional drawing requirements

During the course of the Project, the Employer (or the Engineer) may change the specifications for design drawings from what the Contractor could have reasonably assumed at the signature of the contract – without affecting the design *per se*, only how the design is translated into actual drawings.

For example, the requirements for 'as built' drawings often rely on subjective assessments by the Employer, which can lead to significant delays to the handing over process.

Typical DOI(s): Additional number of drawings (see section 4.4.7.)

4.3.4. Design changes

Design changes vary the amount of work to be done on a project (a change in scope) or, depending on the timing of the changes, they can force some work that had already been completed (correctly) to be redone.

Typical DOI(s): Potentially scope added (see section 4.4.1), design uncertainty (see section 4.4.2) and/or forced rework (see section 4.4.4.)

4.3.5. Design by proxy (by comments, by RFIs…)

This occurs when the Employer injects changes to the design via non-contractual ways, like for example:

- By issuing the changes as comments on design submittals (disguising them as instructions on how to <u>fix</u> the drawings), or
- Including the changes as 'clarifications' in responses to Contractor RFIs, etc.

Typical DOI(s): Potentially scope added (see section 4.4.1), design uncertainty (see section 4.4.2), forced rework (see section 4.4.4), unjustified rejections (see section 4.4.5) and/or excessive reapprovals (see section 4.4.6.)

4.3.6. Fragmented reviews

It is a typical contractual requirement that the Employer submit all comments the first time they review drawing or material submittals. The disruptive event occurs when the Engineer attaches new comments on resubmittals, when nothing would have prevented him/her to attach those comments to the initial submittal. This has the effect of causing rework and delaying the design and construction efforts considerably.

[15] Please note that when we refer to the 'Employer' we include also his agents or other parties not subject to the Contractor's control, like the Engineer, the Construction Manager and/or external stakeholders.

Typical DOI(s): Potentially unjustified rejections (see section 4.4.5) and/or excessive reapprovals (see section 4.4.6.)

4.3.7. Delayed drawing reviews

When a contract includes the submittal and review of design drawings by the Employer, it usually stipulates the maximum time that this review can take. Anything beyond this maximum time delays the project, and thus is disruptive.

Typical DOI(s): Excessive review times (see section 4.4.8.) In the 'But For' simulation, the review of all drawings will occur after the maximum time allowed by the contract.

4.3.8. Cash restrictions

In recent times we often see situations where payments are not made timeously by the Employer, and because of the resulting lack of funds the Contractor (or a Subcontractor) is forced to (a) reduce the manpower (and/or equipment used), or (b) delay the procurement of material.

Typical DOI(s): Staffing constraints (see section 4.4.9.)[16]

4.3.9. Site access restrictions

When work crews cannot access the site as freely as the Contractor expected at the signature of the contract, this may prevent some crews from accessing (a part of) the site, and/or it may reduce the effective daily working hours for others.

Typical DOI(s): Staffing constraints (see section 4.4.9) and/or direct productivity impacts (see section 4.4.3.) If the access restrictions affect a specific area of the works, another DOI could be work on hold (see section 4.4.10.)

4.3.10. Holidays

Major holiday events (like, for example, Christmas or Ramadan) can sometimes significantly affect project staffing levels, hours of work or staff productivity levels.

Typical DOI(s): Staffing constraints (see section 4.4.9), and potentially also direct productivity impacts (see section 4.4.3.)

4.3.11. Weather conditions

Especially severe (and/or prolonged) adverse weather conditions can negatively impact project staffing levels, and reduce the productivity of on-site crews.

Typical DOI(s): Staffing constraints (see section 4.4.9), and potentially also direct productivity impacts (see section 4.4.3.)

[16] If the Contractor or Subcontractor provides full financial records, we may be able to simulate his financial position and derive the staffing restrictions from this.

4.3.12. Work obstructions

This event is similar to "staff restrictions", except that the restriction affects more the work that can be done than the people doing it: i.e., this event describes how some amount of work can momentarily not be executed, irrespective of the number of people available to work on it. The reasons can be many: lack of equipment (e.g. cranes), lack of permits, instructions from the Employer, mishaps, etc.

Typical DOI(s): Work on hold (see section 4.4.10.) Work obstructions could also be expressed as staffing constraints (see section 4.4.9), but this is generally not preferred.

4.3.13. Delayed work inspections

When a contract includes the inspection of construction work by the Employer, it usually stipulates the maximum time within which this inspection should take place – anything beyond this maximum time delays the project, and thus is disruptive.

Typical DOI(s): Excessive inspection times (see section 4.4.11.) In the 'But For' simulation, inspections will always occur after the maximum time allowed by the contract (or which is reasonable, if the contract is not specific about this issue.)

4.3.14. Lack of adequate supervision

Employers often allege inadequate supervision on the part of the Contractor. This can be driven by a reduction in the number of supervisors, and/or by a reduction in their effectiveness (for example, if other Project conditions leave them with less time to manage their teams.)

Typical DOI(s): Ratio of supervision to direct labour (see section 4.4.12.) The inadequacy could also relate to the quality of the supervisors, or to some other structural issue – but these situations are not common and need to be dealt with ad hoc.

4.3.15. Scope deletions

Sometimes an Employer can decide that some amount of work is no longer required, and remove it from the scope of the project.

Typical DOI(s): Scope deleted (see section 4.4.13.)

4.4. Major types of Direct Operational Impacts (DOIs)

This is the data that will be directly used in the simulation model.

Shown below is a template that covers most of the more common events and impacts; however, please note that given the large variety of disruptive events and their potential impacts, it is impossible to define one optimal data gathering template to fit all circumstances and projects.

Item									
1a	Disruptive Event #:								
1c	Title:								
1d	Reference (RCN, EOT,...):								
1e	Description: *(Narrative)*								
		Preliminary design	Final design	Shop drawings	As Built drawings	Purchase orders	Mfg. and delivery	Construction	Notes
2a	Scope Added:								
2b	Date when decided:								
3a	Added Hours:								
3b	Date when Started:								
3c	Date when Finished:								
4a	Scope Aborted:								
4b	Date when decided:								
5a	Scope made Uncertain:								
5b	Date when Started:								
5c	Date when Resolved:								
6a	Scope put on Hold:								
6b	Date when Started:								
6c	Date when Ended:								
7a	Direct productivity loss								
7b	Date when Started:								
7c	Date when Ended:								
8a	Procurement delays:								
8b	Date when Started:								
8c	Date when Ended:								
9a	Review delays								
9b	Date when Started:								
9c	Date when Ended:								
10	Other Impacts?								

Sample generic DOI data gathering template for one disruptive event.

The template shown above ensures two things: it reminds the user of typical potential impacts that an event can have, and also that data for each event should be captured for all Project work phases, not just for one of them.

Sometimes projects are subject to large numbers of a specific type of event (like design changes) – since the number of different DOIs will be much smaller, in this case it might be more efficient to capture the data for all the events in a single worksheet, as shown below:

		Preliminary design		Final Design		Shop Drawings		Construction		
Change ID#	Event title /description	Added Scope	Forced Rework	Added Scope	Forced Rework	Added Scope	Forced Rework	Added Scope	Forced Rework	Date
#1	Event 1									
#2	Event 2									
#3	Event 3									
#4	Event 4									
#5	Event 5									
#6	Event 6									
#7	Event 7									
#8	Event 8									
...	...									

Sample DOI data gathering sheet when dealing with large numbers of similar events.

Finally, please always remember that the impacts described in this document are just those most commonly found on construction projects... but that there are many more.

For example: a disruptive event could also lead to the hiring of less-skilled (or less-experienced) people, critical labour groups could be overloaded with trivial activities (thus diverting them from their main task), it could delay procurement by restricting the flow of material deliveries to site, etc...

For obvious reasons, a successful dynamic disruption analysis always requires the close coordination of the data gathering and the modelling teams; the bi-directional flow of information between these two teams becomes absolutely critical when dealing with non-standard disruptive impacts.

4.4.1. Scope added

An increase in the scope of work.

Data required: magnitude (scope increase) and date when scope change was decided.

Sources: Ideally, scope will be measured in budgeted person-hours, and the Contractor's planning department will have estimated the impact of the change. Alternatively, estimate from project managers.

4.4.2. Fraction of design uncertain

Fraction of the scope of work in design that may be affected by a potential change being discussed. The uncertainty starts when the change is first proposed, and it lasts until it is finally decided. It should at least affect the scope of work directly affected by the change, but usually extends beyond it (since the extent of the actual change is not yet clear.)

It is important to understand that contemplated variations can be very disruptive, whether or not they are eventually instructed. Sometimes, it can take the Employer several months to decide whether a change should be made or otherwise. In such instances, the associated design uncertainty may result in workarounds, relocating crews, waiting, delays on activities etc.

Data required: magnitude (usually expressed as a % of the eventual scope of work involved in the change) and dates when the change was first proposed and when it was finally decided (the latter should obviously coincide with the date for the scope change, see section 4.4.1.)

Sources: Estimate from project managers.

4.4.3. Direct productivity impact

Loss of productivity directly caused by a disruptive event.

For example, site access restrictions that led crews to waste two hours when entering and leaving the site every day would lead to a 25% productivity loss (when people are working 8-hour shifts.)

Scope additions can also be expressed as productivity impacts, especially when the change in scope is not adequately captured by the units of measurement that are used for scope.

For example: incompleteness in project specifications can lead to a 50% increase in the scope of design work, but not alter the number of design drawings to be produced. If we are measuring the scope of design via the number of drawings to be produced, the impact on the scope of work would be more effectively expressed as a 33% productivity loss.

Data required: % productivity loss.

Sources: Estimation by project managers.

4.4.4. Forced rework / obsolescence / abortive effort

Number of drawings / fraction of scope that becomes obsolete because of an event and needs to be redone.

Data required: magnitude (scope to be redone) and date when scope change was decided.

Sources: Ideally, scope will be measured in budgeted person-hours, and the Contractor's planning department will have estimated the impact of the change. Alternatively, estimate from project managers.

4.4.5. Unjustified rejections

Drawing submittals that were rejected for reasons not justified by the contract (for example, because of preferential design, new requirements, etc.)

Data required: % of rejections that cannot be justified contractually.

Sources: Analysis of a sample of rejected drawing / material submittals and the corresponding comments submitted by the Employer.

4.4.6. Excessive resubmittals

Submittals of design drawings that occur after the second submittal.

NOTE: The above assumes that resubmittals by the Contractor will not include any new mistakes that require correcting. This will never be achieved 100%, so this DOI may overestimate somewhat the impact of the Employer and should thus be used carefully. If necessary, an analysis of the comments attached to a sample of second submittals of drawings subsequently resubmitted can be performed to determine the reasons for the need for a third submittal.

Data required: None, this DOI is only included here for completeness' sake (the DOI is a logical switch affecting how drawing resubmittals are handled in the simulation model, and thus requires no data.)

4.4.7. Additional drawings

Increase in the number of design drawings that is not driven by a change to the design, but rather by a change in formal requirements.

Data required: Additional number of drawings.

Sources: Manager estimate.

4.4.8. Excessive review times

Drawing review times in excess of the maximum time allowed for by the contract.

Data required: Average time to review design drawings.

Sources: Submittal logs of design drawings or procurement.

4.4.9. Staffing constraints

A reduction in the manpower employed in a work phase.

Data required: % reduction in manpower, and the start and end times of this reduction.

Sources: Estimates by project managers, ad hoc analyses when available.

4.4.10. Work on hold

Amount of scope that can temporarily not be worked on.

Data required: % scope on hold, and the start and end times for this hold.

Sources: Estimate by project managers, or estimates based on the Project's BoQ.

4.4.11. Excessive inspection times

The time spent waiting for inspections of construction work, beyond the maximum duration allowed for in the contract.

Data required: This direct impact requires two parameters:

a) The maximum duration of work inspections allowed for in the contract.

Sources: Contract clauses.

b) The actual duration of work inspections.

Sources: Inspection logs.

4.4.12. Insufficient supervision

An insufficient number of supervisors to oversee the construction workforce.

Data required: This direct impact requires two parameters:

a) The necessary number of supervisors per 100 direct manpower.

Sources: Estimate from project managers or planners, data from comparable projects.

b) The actual number of supervisors per 100 direct manpower..

Sources: Time sheets, payroll data.

4.4.13. Scope deleted

Scope of work not yet executed, removed from the Contract.

Data required: Amount of work scope removed, time when the decision was made.

Sources: Contract Documents, Correspondence, Engineer Instructions, Final re-measurement, As-Built vs. Contract Documents, Variation Order