System Dynamic Modeling of Delay and Disruption Claims

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ABSTRACT: The construction environment is uncertain, dynamic and complex in nature. The idea that small disruptions and delays can ripple through the project and mushroom in larger, more serious consequences is well established. Nevertheless, it is hard to identify and accurately prove the consequences of such disruptions. The system dynamic (SD) method is presented in this article as a tool that can show the logic link between cause and effect; that is, disruption/delay/acceleration and productivity loss. This in turn helps quantify productivity loss. Because the SD technique recognizes and models the interaction of work activities and graphically illustrates the mechanism by which disruption occurs, the results are accurate and persuasive. This article describes how to establish and use the SD model for acceleration, delay, and disruption purposes with a simple example. The importance and sensitivity of the coefficients in the SD model are also discussed.

KEY WORDS: Acceleration, construction claims, delay, disruption, and labor productivity

Acceleration, delays and disruptions are frequently encountered on construction projects and one of the main reasons for productivity loss. Uncertainties surrounding disruption not only endanger contractor profit margins but also make parties less amenable to settlement. This consequently delays the resolution of disputes and increases costs for all concerned.

Owners prefer to know the full cost impact of any proposed change prior to its authorization. Contractors, on the other hand, prefer to claim impact costs based on a single, overall calculation oftentimes submitted after project completion. A stalemate may result, poisoning change negotiations and driving up costs.

The system dynamics (SD) approach is a tool for quantifying such complicated impact costs. By recognizing the specific characteristics of and interactions between schedule activities, the SD model can simulate disruption throughout the entire network. Because it is a graphical illustration of the project and the changes to the project, SD is useful for visualizing and understanding these project triggers, and the acceleration, delay, and disruption that results. This in turn helps pinpoint responsibility for the change and estimate the quantum of the change.

The purpose of this article is to illustrate how to use the SD method by modeling a simple example. One of the most important parameters in establishing the SD model is the coefficient that quantifies the correlation between two adjacent schedule activities. The importance of accurately estimating those coefficients is also discussed in this article.

SYSTEM DYNAMIC APPROACH

The SD approach is based on a comprehensive view of the project and focuses on the feedback processes that take place within the project system. It offers a rigorous method for the description, exploration, and analysis of complex project systems comprised of organizational elements, the project work packages and the environmental influences [8].

Kenneth G. Cooper [1, 2] used the SD approach in the Ingalls Shipbuilding case against the US Navy in the late 1970s. This case involved owner (US Navy) delays, mainly stemming from design changes. The total settlement was $447 million. The model was the basis for at least $200-300 million of this settlement [2]. Since this important precedent, the method has been used in litigation, though to-date still outside of construction. Part of this lack of acceptance is because of its retrospective, rather than contemporaneous nature.

In essence the SD model provides a simulation of project performance as the project is built, including both customer changes (e.g., design changes) and varying project conditions (such as the labor market, regulatory changes, etc). The numerically validated model can then be used to simulate the project as it would have occurred in the absence of changes. The difference between "what happened" and "what would have happened" is the full impact of those changes and the disruption [1, 7].

There are four purposes of a SD model:

1. Demonstrate causality—show what events triggered a disruption and how the triggers propagated through the project.
2. Assign responsibility—identify the party responsible for these impacts.
3. Quantify the impact—show that the events that caused acceleration, delay or disruption, and created a specific time and cost overrun in the project.
4. Convince the project stakeholders of points 1, 2, and 3.

There are seven principal steps to establishing a SD model:

1. Identify the scope of each work activity.
2. Assign the original workhours to each activity.
3. Establish a network to model the relationships between the work activities.
4. Identify the causal relationship between each work activity and assign the coefficients. Some predecessors might have substantial impact (high coefficient value) to the successor, some might have very slight impact (low coefficient value), and some might have no impact at all (coefficient is zero).
5. Calculate the accelerated, delayed or disrupted hours to an activity by multiplying the coefficients of all its predecessor(s) against its work hours.
6. Add the total affected hours for all activities in this iteration.
7. Repeat step 6 until the impact of an iteration is negligible. Sum the affected hours of all activities in all iterations.

There are some problems with SD that prevents its widespread use and acceptance by courts. Howick, for example, noted that the SD models are frequently drawn in too limited a fashion [5]. Disruptions on an adjacent project may not be captured when modeling a second project. Similarly, modeling work of one subcontractor may exclude impacts associated with other subcontractors.

Susan Howick [6] also explored criteria that should be used to identify whether a situation could be modeled using SD. Her criteria are:

1. Does the situation contain feedback loops and can those loops explicitly model the situation?
2. Is there sufficient, reliable information and data available?
3. Will SD modeling explain the project more clearly than some other modeling technique?

One other criterion is whether the dispute justifies the amount of time and effort required to model the situation.

APPLICATION FOR DELAY CLAIM—AN EXAMPLE

An example from Colin Eden is adapted here to illustrate how to quantify labor productivity loss caused by owner's delay in decision-making [3].

An owner hired a contractor to make modifications to his house. The contract is fixed price and involves modifications to a bedroom, kitchen, and bathroom.

Half way through the contract the carpenter was working in the bedroom laying a new wooden floor. The plumber

Activity	A	B	C	D	E	F	G
Workhours	20	50	50	30	20	20	20
Owner	4	0	0	0	3	0	0
1st from A	0	10	10	0	0	4	0
1st from B	0	0	7.5	0	0	0	0
1st from C	0	5	0	3	0	4	30
1st from D	0	0	5	0	0	0	0
1st from E	6	0	0	0	0	0	0
1st from F	4	0	0	0	20	0	0
1st from G	0	0	10	0	0	0	0
1st cycle total	14	15	32.5	3	23	8	30
2nd from A	0	0	6.5	0	0	1.6	0
2nd from B	0	0	4.9	0	0	0	0
2nd from C	0	1.5	0	0.3	0	0	30
2nd from D	0	0	3.3	0	0	0	0
2nd cycle total	0	1.5	14.7	0.3	0	1.6	30
3rd from B	0	0	2.2	0	0	0	0
3rd from C	0	0	0	0	0	0	0
3rd from D	0	0	1.5	0	0	0	0
3rd cycle total	0	0	3.7	0	0	0	0
Grand total	14	16.5	50.9	3.3	23	9.6	60

Total delay=177.3 workhours
Total original schedule=210 workhours
Percentage of delay=177.3/210*100%=84.4%.

Table 1— Delay Calculation With the Original Coefficients

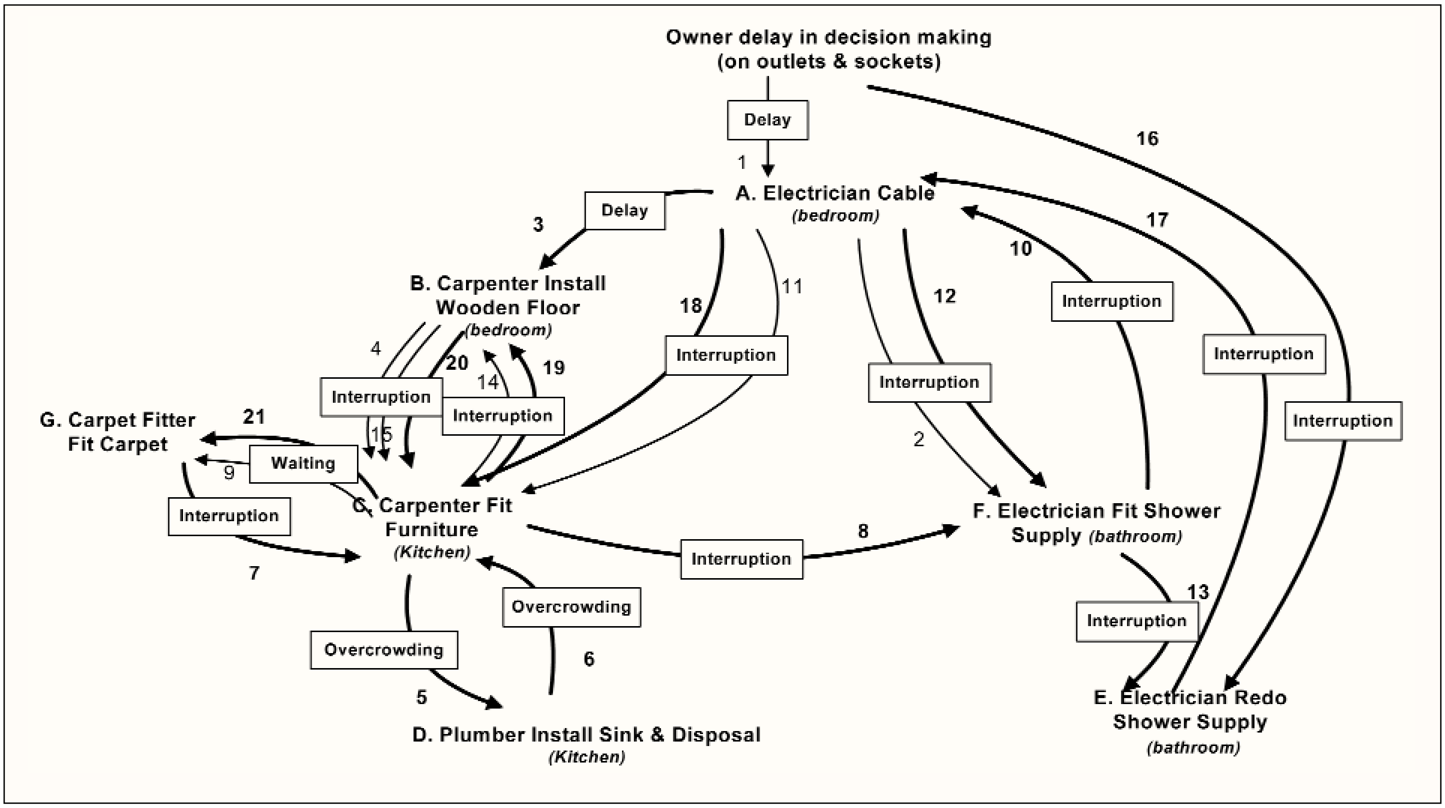

Figure 1— The SD Model for Disruption and Delay Analysis

Link	A-B	A-C	A-F	B-C	C-B	C-D	C-F	C-G		D-C	E-A	F-E	F-A	G-C
Iteration	1	2	2	3	2	3	1	2		3	1	1	1	1
Original	0.2	0.2	0.2	0.15	0.1	0.1	0.2	1.5	1*	0.1	0.3	1	0.2	0.2
105%	0.21	0.21	0.21	0.1575	0.105	0.105	0.21	1.575	1.05*	0.105	0.315	1.05	0.21	0.21
Total delay	177.76	178.41	177.53	178.22	177.88	177.72	177.78	180.53	179.03	178.20	177.83	178.53	177.73	178.315
95%	0.19	0.19	0.19	0.1425	0.095	0.095	0.19	1.425	0.95*	0.095	0.285	0.95	0.19	0.19
Total delay	176.66	176.03	176.89	176.28	177.19	177.35	177.29	174.73	176.03	176.87	177.23	176.53	177.33	176.752

* the second link of C-G

Table 2— Security Analysis of the Coefficients

was working in the kitchen moving the sink and installing a new waste disposal unit. The carpenter realized that the owner had not yet told the contractor (his employer) where the owner wanted his new power outlets and telephone sockets. As a result the electrician was unable to lay the cabling which would allow the carpenter to close the flooring.

So, the carpenter decided that the best thing was to work around the problem by laying most of the floor. That carpenter then moved to installing the kitchen cabinets early, in order to keep working. But it got crowded in the kitchen with the carpenter and plumber fighting for space, and their work was slowed because of the congestion.

The carpet layer arrived at the jobsite on time to start work in the bedroom, which meant the carpenter had to get the electrician to complete the cabling. This resulted in an interruption to the electrician, who had been installing the power supply to the new shower in the bathroom. However he changed tasks and made his best guess on the location of outlets, which would allow the carpenter to lay the floor. This meant that the carpenter stopped working on the kitchen cabinets.

While all these activities were being worked on by the electrician and carpenter, the carpet layer waited. Unfortunately, after the electrician and carpenter finished working on the floor, the owner notified them to relocate the power outlets and telephone sockets. (The carpenter's guess about the sockets was wrong and rework resulted.) This delayed the carpet layer. And even though the electrician is competent and experienced, he mistakenly omitted part of his work in the bathroom when he went back to the previous task.

An activity-level SD model for this small example is presented in Figure 1. From steps 1 and 2, the scope and work hours of each activity are identified; see Table 1.

In step 3 the logic sequences of 21 links are established. In this model each work activity represents a separate joint as in a structural frame. For example, arrow 1 shows the owner-caused delay to electrician when he was working in the bedroom. Arrow 2 shows that the electrician could not finish cabling and diverted to work in the shower.

In step 4 the causal coefficients are developed according to the relationship of the two activities and the "stiffness" (to borrow terminology from network methods of structural analysis) of the successor activity. If an activity has no disruptive effect on its successor activity, the coefficient of the causal relationship linking the two activities will be 0. Though a more complicated situation, the coefficients can be allowed to change as the model cycles through different iterations [4]. Step 5 computes the total delay of the current iteration. The process is continued until further iterations result in minimal impact; see Table 2.

The results are presented in Table 1 for three iterations. For this example the delays are 125.5, 48.1, and 3.7 hours in the first, second and third iteration, respectively, meaning a grand total of 177.3 hours.

From Table 2 it can be seen that activity G is the most seriously delayed. Even though the carpet layer arrived on time, he could not start to lay the carpet until the wooden floor was finished. So in the first iteration 30 extra hours were spent to solve all the problems associated with the owner's delay in decision-making.

The total delay time in this example is 177.3 hours. The original total labor hours needed to finish these six activities was 210 hours. The results show that owner's delay affected the labor productivity significantly, by 84.4%. Table 1 also shows that the indirect labor productivity loss is much more than the direct labor productivity loss: 7 hours vs. 170.3 hours. In practice this indirect, ripple impact is usually hard to prove and very arguable. The graphical nature of the SD model helps to demonstrate such ripple effects.

SENSITIVITY ANALYSIS OF THE COEFFICIENTS

One of the most important tasks in establishing the SD model is to estimate the coefficient values. Coefficients represent how much disruption ripples through the network. The analyst has a choice of how to define these coefficients. They can be based on either the predecessor or successor activity's workhours. In this example they are based on the successor activity's workhours because a delay to the successor activity is highly dependent on the characteristics of the successor activity. For example, the material, equipment, working space, and supervision constraints of an activity have significant influence on its own productivity performance. In other words, when the coefficient of A-B = 0.2 in the first iteration, the B (50 workhours) activity is delayed by 10 (0.2*50=10) hours.

These coefficients are a function of the linked activities' locations, times of performance, types of work, crew sizes and compositions, supervisors, and numerous other factors. Specifically, productivity impacts can be caused by factors such as work area congestion, resource diversion, skill dilution, stacking of trades, waiting for shared equipment, and dilution of supervision. When estimating these coefficients we need to collect information that includes each of these factors. More than the two directly linked activities may need to be considered. For example, when the coefficient for C-G was estimated, we considered all the activities delayed before activity G could start, because it represents the time the carpet layer had to wait. For the first iteration, 30 extra hours were wasted before the carpet layer received the notice to start. For the second iteration another 30 extra hours were spent.

Estimating the coefficients is not easy, yet very important to accuracy of the SD model. To underscore the importance of accurate coefficients, Table 2 is included to show what happens when the coefficients are changed by just +/- 5%. When the coefficient for link C-G1 increases 5%, from 1.5 to 1.575, the total delayed hours increase from 177.3 to 180.5. Figure 2 illustrates how the total amount of delay hours change as this one coefficient changes. Any SD analysis should include such a sensitivity analysis.

SD modeling is one effective tool for quantifying productivity loss. The concept and process proposed in this article can be used in acceleration, delay, and disruption claims. It is especially useful to quantify and portray indirect (ripple) productivity losses and to determine which activity causes the largest amount of delay and which activity is delayed most in a particular project.

The example is presented to show the SD methodology. The values derived in this analysis are strictly hypothetical. The importance of coefficient estimation is also discussed in this article. In the simple example presented in this paper, even a 5% increase or decrease in a single coefficient causes a notable difference of the result from the SD model.

Further research is still needed to develop criteria that help quantify these coefficients. The authors are pursuing such. ◆

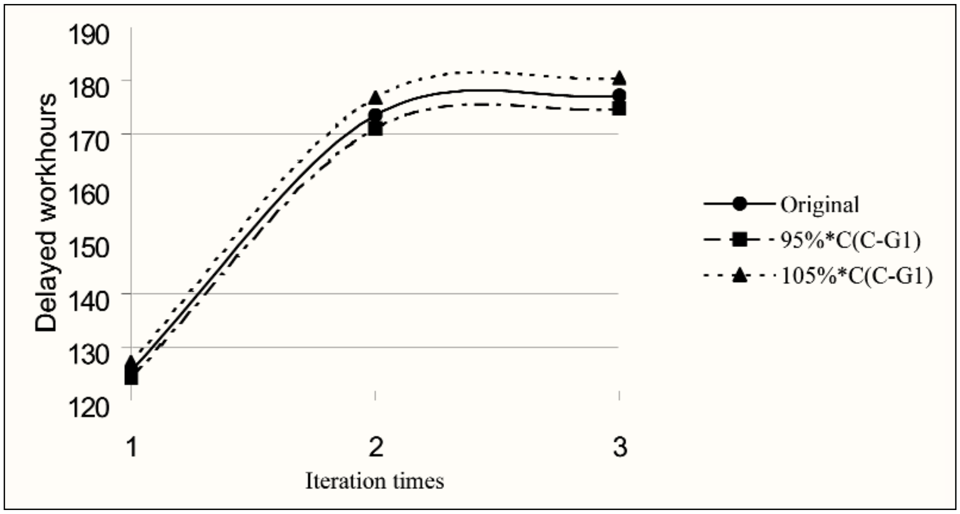

Figure 2— Sensitivity Analysis of the Coefficients

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