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Simulation of Execution Alternatives Using Chronographic Scheduling Logic

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***Abstract*-The more complex a project is, the more attractive non-traditional project delivery methods like Design-Build become. These delivery methods allow decisions with several options to be postponed. To account for these alternatives, existing generalized scheduling methods integrate decisions into their processes; however, these methods only use traditional precedence dependencies for network calculations. This paper contributes to the existing body of knowledge by extending the traditional logic and modeling execution alternatives using chronographic time-scaled point-to-point relations, production-based dynamic relations and function dependencies between ongoing activities. Using the Monte-Carlo simulation, the paper simulates the impact of operations and reworks uncertainties for the execution alternatives. For companies, this approach represents scheduling constraints in a flexible manner and provides a feasible solution for modeling the complexity of real-world projects.**

Keywords- Simulation; Execution Alternatives; Uncertainties; Chronographic; Scheduling; Project; Construction

I. INTRODUCTION

For highly complex projects, or those carried out under the principles of concurrent engineering, in which design and construction run parallel, many decisions are postponed. As more information becomes available over time and the level of risk decreases, it becomes much easier to make better-informed decisions according to the status of the project or based on the available budget. For example, infrastructure projects such as roads, railways and pipelines are linear and pass through a long territory. Their effects are not localized, which increases their impact on the environment, human beings and the social and economic aspects of an entire region. Besides the main customers and professionals, many stakeholders could be involved in the project's different ministries, including transportation, environment and finance; the cities and their territory, traffic and asset services; agricultural protection and railways agencies if the road interferes with them; and the companies that own the aerial and underground networks, such as electricity, natural gas, telephone lines and wiring digital data. Lastly, there are also the merchants and citizens concerned by the project zone.

The growing number of stakeholders with different agendas and a flow of events that is continually changing accounts for part of the complexity [1] and increases the number of alternatives and multiplies the changes on the initial project throughout the design and execution phases. Thus, various scenarios should be compared before making informed decisions. Each scenario possesses its advantages and disadvantages in term of quality, cost and duration. The scheduling method should be able to model and simulate this reality. For example, on Montreal's South Shore, Highway 30 crosses cities, agricultural areas and major rivers. Another example is the reserved bus lane on Pie IX Boulevard in Montreal, which impacts residents, merchants, traffic and underground networks of a main road artery. Several stakeholders may be involved in these projects.

One must also understand that the needs of owners are evolving in order to adapt to economic and technological changes. Industrial or hospital construction and renovation projects are good examples. These projects are particularly complex, and their duration, including the design and implementation, are spread over several years. These projects can integrate countless mechanical, electrical and miscellaneous services and specialized equipment. Technology also changes and new equipment may require changes in the size, structure or the envelope of laboratories and rooms given the weight, vibrations and need for protection against the rays emitted by the new equipment. Also, some stakeholders are not experts, and once they see the physical project, their requests become more specific. In the case of major hospital projects, few physicians understand the construction industry; as such, the definition of their needs can be partial and inaccurate in the initial stages of the project. It is therefore not unusual for them to request changes at the last minute after physically seeing the project.

Many of these projects are subject to public hearings, and there are many stakeholders in favor of or opposed to them. From the project identification, through its design and construction and until its completion, several changes can arise from major or minor design details. The more complex a project is, the more uncertainty has to be integrated into its network calculations, and execution alternatives have to be explicitly integrated into its algorithm. Complex projects are also too unpredictable and multidimensional to be represented by simple models. These projects require more flexibility in design and the development of suitable management methods that allow for adaptation to changes. These methods must be able to model various alternative scenarios and simulate their impact on the project duration, cost and quality.

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Traditional scheduling networks, known as the Critical Path Method (CPM), include the Arrow Diagram Method (ADM) and the currently widely used Precedence Diagram Method (PDM). These deterministic methods do not associate any uncertainty with activity duration, costs and execution sequences. By proposing only external constraints and simulating work production through lags, the Precedence logic lacks precision. This lack of precision usually occurs for one of the three following reasons: i) via the reverse critical path, which is common; ii) when using some type of relation (e.g. Finish-to-Finish) and delay (positive or negative lag) with multiple calendars; iii) when two or more activities depend on each other during their execution processes, which is also common [2]. The numerous errors produced by these types of networks diminish the reliability of the schedule and impair the internal monitoring of activity interdependencies.

To overcome these gaps, the Chronographic Method [3] models the schedule logic by suggesting internal divisions of activities by workload. For example, activity X is divided into three sections: X_1, X_2 and X_3. A new point-to-point relationship (Fig. 1 - P1a) connects any two activities in order to represent a precedence relation. A connection point can be the start of the activity, the end of the activity or any of its internal divisions. Fig. 1 - P1b demonstrates connection point X_{1E} at the end of the first section of activity X. The chronographic production-based relations or functions [2] extend the role of the point-to-point relation to a dynamic relationship between the interlinked activities and allow probabilistic dependencies between activities, which means that they allow gaps between these interdependencies (Fig. 1 - P2). These gaps represent the variance of time or quantity linked to the connection point. Dynamic relationships can represent the case of one-way dependencies in which the successor activity depends on the production rate of the predecessor activity (Fig. 1 - P3), or a case of two-way dependencies where the two activities depend on each other (Fig. 1 - P4). The comprehensive results of this logic can be found in papers [2] and [3].

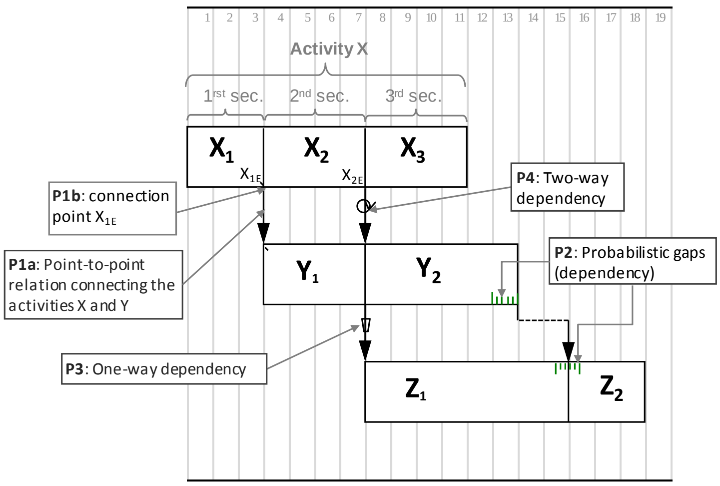

Fig. 1 Point-to-point, probabilistic and dynamic interdependencies between activities

The use of multiple relations helps to track interdependencies between two ongoing activities without having to split activities and overload the schedule unnecessarily. For instance, activities X and Y are connected by two relations. The 1st relation connects the end of the first section of activity X with the start of activity Y, while the second is a two-way dependency that interlinks the progress between the third section of activity X and the second section of activity Y. In the latter case, any delay in the third section of activity X or the second section of activity Y will affect the other section.

The Program Evaluation and Review Technique (PERT) [4] was a first step toward applying uncertainties to activity duration. In 1962, Eisner [5] introduced the concept of the generalized PERT, a stochastic model incorporating decision boxes into the network to allow alternative choices. With this concept, all activities do not have to be completed to terminate the project. Generalized methods may represent uncertainties in most of the constraints, including execution sequences. Paper [6] furthered that work by proposing the Graphical Evaluation and Review Technique (GERT). It consisted of nodes (events representing operations) and directed branches (connecting the nodes). Paper [7] developed the Decision CPM Method (DCPM) and proposed several possibilities using a single graph schedule. Building on previous studies, paper [8] developed a Venture Evaluation and Review Technique (VERT) to assess risks within the networks. Paper [9] described a Fuzzy Network Technique for large and complex systems; however, these techniques generally apply traditional CPM networks to their calculations. These networks use only external relationships between activities and inherit their limits. None of these techniques employ internal or continuous interdependencies between ongoing activities to simulate the real conditions of production and activity criticality. These limitations affect the computation of the schedule and may produce erroneous results in several cases, as cited above. Moreover, several papers that study simulation models that provide production-based linking structures have discussed the limitation of using time as the only constraint required for the relationship between activities.

SimCon has been developed using a simulation-based project that uses flexible logical sequences and various scheduling alternatives [10]. Stroboscope by [11] considered uncertainties in all aspects of the project, including by dynamically selecting

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the routing of resources and the sequence of operations. Due to their cyclical logic, these simulation models are well suited to modeled repetitive projects and are powerful tools for optimizing the production process; however, by providing many more details compared to traditional networks, they require more time for modeling activities. In addition, their cyclic links may be complex in the case of multiple and continuous links between two or more processes. For these reasons, these models have not proven their effectiveness for complex modeling non-repetitive projects.

The main goal of this research is to overcome the shortcomings of the current methods cited above by studying and simulating execution alternatives, including different types of uncertainties, and modeling the impact of non-chosen alternatives on the project schedule. The critical path calculation and the criticality of each activity or section are based on the chronographic logic. The proposed method is a schedule method suited for complex schedule projects that include various scenarios. Although the proposed method can be applied to plan projects executed with traditional delivery contracts such as Design-Bid-Build (DBB), it is more useful for contracts that run under the principles of concurrent engineering, such as Design-Build (DB) and Integrated Project Delivery (IPD). With traditional delivery methods, the design, bid and construction are executed successively as separate steps, leaving little room to adapt the design and to study the value of the project throughout its execution.

II. CHRONOGRAPHIC EXECUTION ALTERNATIVES AND DECISION POINTS

For non-traditional contracts, such as Design-Build projects, planners often prefer to delay the decision to choose between different execution alternatives so that the evaluation is done according to the requirements of the situation. Alternatives may impact project quality, cost and time differently. These uncertainties are represented by probabilities that assess levels of compliance with various constraints.

Chronographic modeling suits this need by proposing a generalized time-scale network [12]. Figs. 2 and 3 demonstrate an example of execution uncertainties where two alternatives are involved, namely:

- Option B-op1 will be executed through activities B-op1-1 and B-op1-2 with a 60% chance of being executed;
- Option B-op2 uses activities B-op2-1 and B-op2-2 with a 40% chance of being executed.

Chronographic logic associates a decision point with temporal functions (relationships between activities) to allow the manager to choose between alternatives. In these two figures, the manager chooses alternative B-op1 as the most probable solution. This alternative is integrated into the schedule for critical path calculation purposes. If the second alternative is chosen during execution, the project duration is likely to change. The total project duration has to take this fact into consideration. To adjust the project's total duration, the Chronographic method adds a temporary function called the Probability Entity, which adjusts overall project duration, cost and quality according to the chosen alternatives. Probability Entity is represented graphically by a spring. The Probability Entity duration is calculated based on the sum of the products of the duration of each activity by its respective probability minus the duration of the chosen alternative. The second alternative, B-op2, is placed on hold for possible implementation. This second alternative is drawn with a dotted line in a light color and can be plotted on a different layer, which can either be shown or hidden as needed for visual clarity. The objective of modeling the execution alternatives and simulate the impact of non-chosen alternatives on the project schedule has been fulfilled.

Fig. 2 models the execution alternatives using point-to-point relations and shows an example with two alternatives. In this figure, the point-to-point relations are associated with a probabilistic gap entity. The internal dependencies between any two activities may be probabilistic, which means that they permit a certain gap in the interdependence of activities.

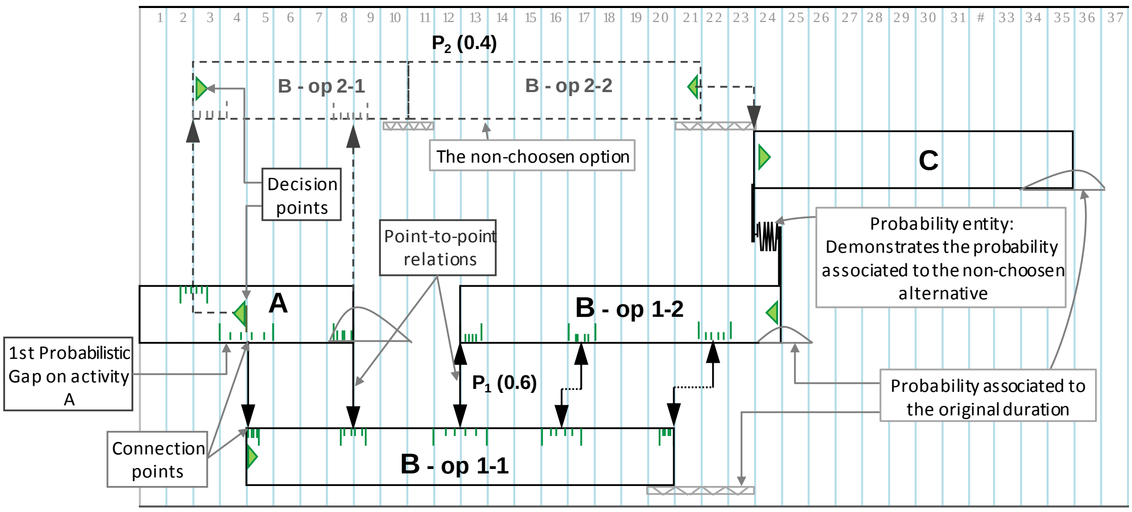

Fig. 2 Execution alternative using dynamic relations

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For example, as a successor activity, activity “B-op1-1” allows for a certain amount of flexibility in the work to be accomplished with its two point-to-point relations with activity A as a predecessor activity. The Earliest Early-Start (EES) of activity “B-op1-1” is equal to the 4th day (date of the 1st connection point on activity A) - 1 day (50% of the 1st Probabilistic Gap on activity A) – 0.5 day (the 1st Probabilistic Gap on activity “B-op1-1”) = the day 2.5 from the start of the project.

The Latest Early-Start (LES) of activity “B-op1-1” is equal to the fourth day (date of the first connection point on activity A) + 1 day (50% of the 1st Probabilistic Gap on activity A) = the fifth day from the start of the project. The amount of flexibility in the Early-Start (ES) of activity “B-op1-1” is equal to the day 5 – day 2.5 = 2.5 days.

The same rule applies to all other relations in this example, which adds flexibility to the schedule. Otherwise, for each variation in production, even minor ones, the successor activity can be delayed or interrupted if it has already started. The proposed method, then, presents a more practical solution that simulates actual site conditions. In the real world, dependencies between activities accept certain amounts of production variations without affecting the schedule, even if the existing methods are unable to represent them graphically or take them into account in their calculations.

Fig. 3 shows the same example while using the probabilistic dynamic function between activities. The multiple internal interdependencies between activities are replaced with a one-way or two-way continuous (or section by section) mathematical function associated with a single temporal function. Graphically, one-way dependency is represented by a trapezoid and two-way dependency by a loop. The mathematical function tracks the internal variation in production, adjusts the successor activity for the one-way dependencies and adjusts both the predecessor and successor activities when using the two-way dependencies. The comprehensive results of this one-way and two-way logic can be found in paper [3].

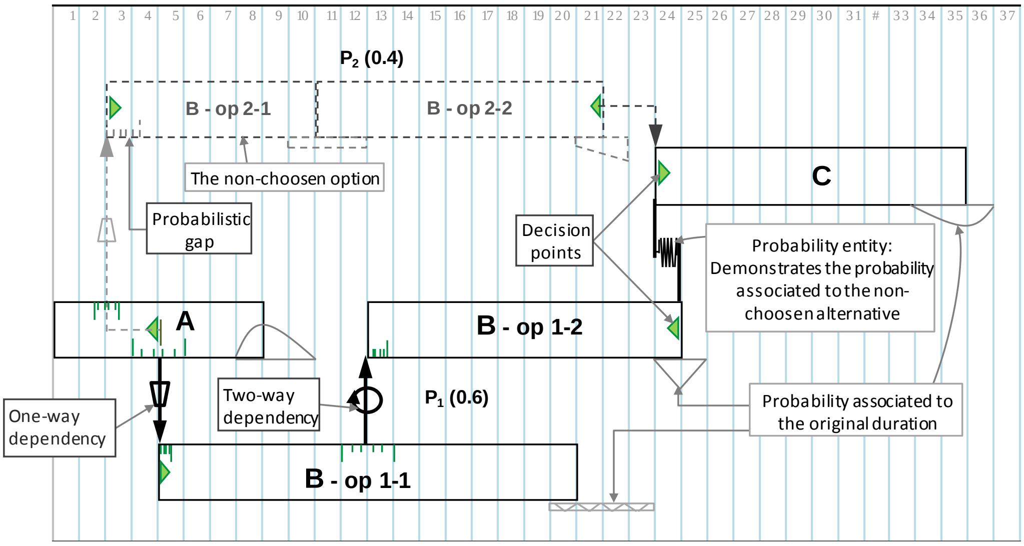

Fig. 3 Execution alternative using dynamic functions

III. SIMULATING ALTERNATIVES WITH THE CHRONOGRAPHIC LOGIC

A. Simulation Methodology

This paper models and simulates the activity execution alternative, studying the impact of the non-chosen alternatives on the project schedule. The critical path calculation and criticality of the activities are compared using the Precedence and Chronographic logic. Probabilities are associated with duration and relation when available.

Using Monte Carlo simulation, 10,000 random draws are conducted. For each draw, an execution alternative is selected, including its activities and relations uncertainties. Results are assembled into a probability distribution to demonstrate probable durations and their occurrence probabilities.

1) Modeling Execution Options

When several alternatives exist, the project schedule is calculated based on the selected alternative. If a second alternative is chosen during the project execution, the project duration, cost and quality are likely to change. Therefore, the total project duration has to take this fact into account.

Imagine a project with twenty decision points. Each decision normally has several execution alternatives. Each alternative has a chance of being executed. Assume that the manager decides to simulate the project with ten thousand random samplings. For each draw and on each decision point, an execution alternative is chosen randomly, considering the probability of each alternative. The Probability Entity duration, included with each alternative decision, is equal to the random duration minus the duration of the preselected alternative.

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2) Modeling Execution Uncertainties

Uncertainties are linked to the activity duration and the interdependencies between activities. The original activity duration may be uncertain. For each draw, a random duration is chosen for each activity based on the probability distribution. External and internal workload interdependencies follow the Chronographic logic and equations. Reworking may occur when the production of the dependent activity is affected by the output fluctuations of the independent activity. Overlapping between activities and sections may also cause reworking. The Chronographic logic defines the sensitivity range limits (or overlapping limits) between activities and the maximum impact (or reworking due to the additional overlapping).

In Fig. 4, Activity B-op1-2 depends on Activity B-op1-1. The relation is a two-way dependency, internal-to-start with a probability lag of two days (± one day) on Activity B-op1-1 (see green scale) and one day on Activity B-op1-2. To compress the project, the overlapping limits are six days on Activity B-op1-1 and five days on Activity B-op1-2. The overlapping limits show the maximum overlapping between activities.

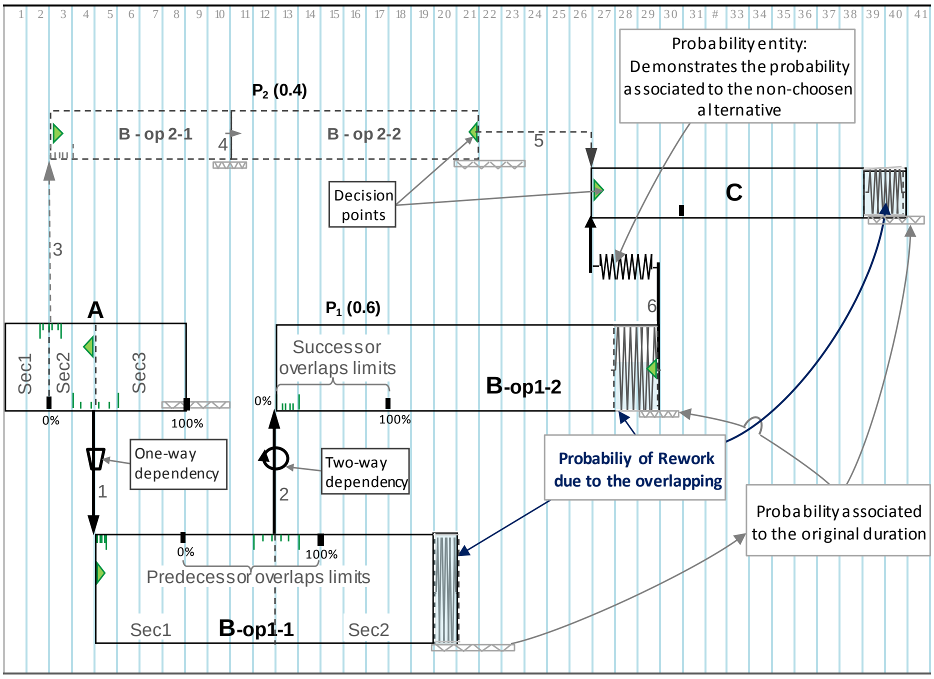

Fig. 4 Combining the execution uncertainty, doubtful result and acceleration process

For each draw, the duration of each Probability Entity is chosen randomly between zero and the maximum rework duration. The objective of simulating the uncertainties using the Chronographic logic has been fulfilled.

B. Validation Schedule

The methodology has been validated through the project schedule shown in Fig. 4. In this figure, the simulation used the Chronographic schedule logic combining execution alternatives and uncertainties. This simulation is compared with the Precedence logic (Fig. 5), showing only the execution alternatives.

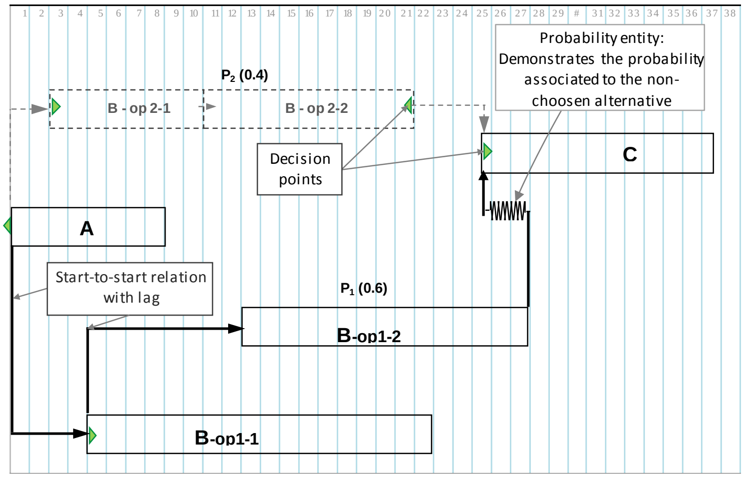

Fig. 5 Execution uncertainty using the Precedence logic

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The example illustrates a project with four activities: A, B1, B2 and C. There are two alternatives for the execution of activities B1 and B2. The first option includes the two activities with a 60% chance of being executed, B-op1-1 and B-op1-2, and the second option includes the two activities with a 40% chance of being executed, B-op2-1 and B-op2-2.

Table 1 provides details on the project activities. Activity A has three sections, while activity B-op1-1 has only two sections. The other activities have no sections. For each activity or section, the table indicates the duration, the probability that the activity is selected (100% means that there are no alternatives and the activity has to be executed) and the operation probability (optimistic and pessimistic duration).

TABLE 1 PROJECT ACTIVITY DETAILS

Activity	Section	Duration (d)	Probability		
			Execution	Operation	
				Opt	Pess
A		**8d**	**100%**	**-10%**	**25%**
	sec 1	2d			
	sec 2	3d			
	sec 3	3d			
B-op1-1		**14d**	**60%**	**-5%**	**15%**
	sec 1	8d			
	sec 2	6d			
B-op1-2		**15d**	**40%**	**-5%**	**5%**
B-op2-1		**8d**	**100%**	**-10%**	**10%**
B-op2-2		**11d**	**100%**	**-10%**	**20%**
C		**12d**	**100%**	**-5%**	**10%**

Table 2 illustrates the six existing relationships between the activities. For each of these relationships, the table specifies the following:

- Relationships: Point-to-point with gap; one- or two-way relationships;
- Connection points and gaps for the predecessor and successor activities;
- Predecessor and successor overlap limits and maximum rework.

TABLE 2 RELATIONSHIPS BETWEEN ACTIVITIES

Nbr	Type	Predecessor		Successor		Predecessor overlap			Successor overlap		
		Activity (Point)	Gap	Activity (Point)	Gap	Start	Finish	Max rework	Start	Finish	Max rework
1	One-way-function	A-sec2 (Finish)	±1d	B-op1-1-sec1 (Start)	+0.5d	2nd d	8th d	-	-	-	3d
2	Two-way-function	B-op1-1-sec1 (Finish)	±1d	B-op1-2 (Start)	+1d	4th d	10th d	3d	0	5th d	6d
3	Point-to-Point ± Gap	A-sec1 (Finish)	±0.5d	B-op2-1 (Start)	+1d	-	-	-	-	-	-
4	Point-to-point	B-op2-1 (Finish)	-	B-op2-2 (Start)	-	-	-	-	-	-	-
5	Point-to-point	B-op2-2 (Finish)	-	C (Start)	-	-	-	-	-	-	-
6	Point-to-point	B-op1-2 (Finish)	-	C (Start)	-	-	-	-	0	4th d	3d

C. Simulation Results and Discussion

Fig. 6 demonstrates the simulation results of the project. Fig. 6.a shows graphically the total duration of the project. It uses the two examples of Figs. 4 and 5 and Tables 1 and 2 to model the project through the Chronographic logic and the Precedence logic. For each of these two examples, the project is simulated 10,000 times using Monte Carlo simulation. For each draw, random values associated with the duration of the chosen alternative and the probabilities associated with activities and relations are selected and the network is calculated.

Using the Chronographic logic, the total duration of the project varies between 36.1 and 55.6 days. This major disparity results from the difference between the average duration of option 1, which is selected in 60% of draws, and option 2, which is chosen in 40% of draws. The first reveals a distribution with a minimum duration of 36.1 days and a maximum value of 40.3 days, when the second execution alternative (activities B-op2-1 and B-op2-2) is chosen. The second zone presents a

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distribution with a minimum duration of 43 days and a maximum value of 55.6 days, when the first execution alternative (activities B-op1-1 and B-op1-2) is chosen. It is extremely unlikely that the project will end within 40.3 to 43 days.

In Fig. 6.b, the results of the iterations are assembled into cumulative and non-cumulative probability distributions. The non-cumulative distribution shows two distinct zones for option 1 and option 2. The cumulative distribution shows the probability of occurrence for each project total duration.

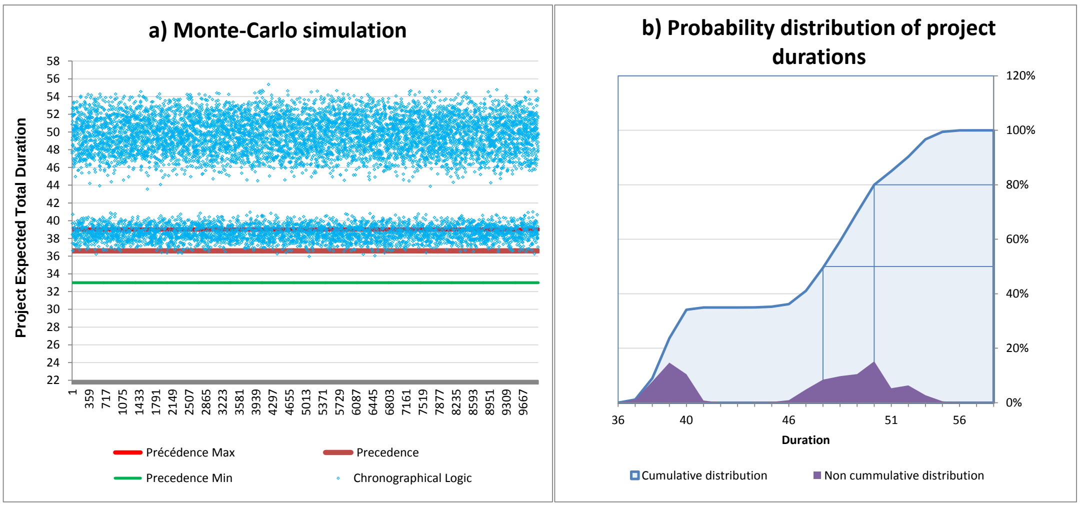

Fig. 6 Monte-Carlo simulation results and cumulative and non-cumulative probability distribution of project duration

With the Precedence logic, which only takes into account the execution alternatives without any associated uncertainties, the most probable project duration is 36.6 days. The duration would be 39 days if Alternative 1 were chosen and 33 days if Alternative 2 were chosen. The difference between the total duration of the Precedence and Chronographic logic is caused by the implementation of the Chronographic logic to the schedule when simulating the execution alternatives and while taking into account the uncertainties associated with operations, processes and uncertain results.

The simulation method and the results show the impact of execution alternatives on the total project duration. Each duration has a different cost. This cost depends on the chosen alternative and varies according to the costs linked to the different uncertainties. Alternatives usually vary and may impact the project quality, cost and time differently. The simulation data should also link each alternative to a quality weight. Thus, the various scenarios of a project, of which many components include more than one alternative, can be compared in terms of their overall weight. Table 3 shows an example of the calculation of the relative weight of each scenario. The management team attributes the relative weights based on the importance of cost, execution time and final quality. In this example, the management team has assigned a weight of 40% for quality, 40% for the cost and 20% for the duration. The relative value of each scenario is the weighted value of its cost, duration and final quality multiplied by its respective weight. Scenarios can therefore be compared using these values. Thus, in this example, Scenario 1 will be the chosen option.

TABLE 3 RELATIVE WEIGHT OF EACH SCENARIO

Relative weight	40%	40%	20%	
	Quality	**Cost**	**Duration**	Weight of
Unit	%	M$	weeks	the scenario
Initial solution	100%	5.00 M$	40	10.40
Scenario 1	**105%**	**5.25 M$**	**42**	**10.92**
Scenario 2	85%	4.70 M$	35	9.22
Scenario 3	120%	6.00 M$	40	10.88

IV. CONCLUSION

In construction projects, many factors can delay decisions. In response to this problem, this paper simulates activity execution alternatives while taking uncertainties into consideration. Execution alternatives and uncertainty calculations were based on the Chronographic logic for tracking the workload and one- or two-way interdependencies between two ongoing activities based on probabilistic point-to-point and continuous relations. The simulation result provides a probability distribution that allows the decision maker to select the project duration using the cumulative probability distribution based on his or her risk aversion. This distribution is compared to the Precedence logic without any associated uncertainties. This paper contributes to the existing body of knowledge by modeling the execution alternatives and uncertainties using chronographic time-scaled, point-to-point relations, production-based dynamic relations and function dependencies between ongoing activities.

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Some restrictions may limit the use of the proposed method, in particular the requirement to integrate the proposed method with existing commercial software. We can also note that the preparatory scheduling work will be more demanding and will need more advanced training. The visual aspect may also be compromised by the complexity of the schedule; however, this gap can be mitigated by using the chronographic organization approaches described in previous publications and by plotting the schedule information on different layers.

Despite these limitations, this method remains attractive for planners as it provides greater flexibility in planning complex projects, which produces more realistic schedules while increasing the precision and accuracy of results. The results demonstrate the impact of applying the Chronographic logic to schedules when simulating activity execution alternatives and taking uncertainties into account. The consumer-controlled adaptability of the schedule will provide a better simulation of construction site conditions and will also reduce effort during ongoing updates. In conclusion, the proposed method is a new way of implementing constraints to simulate real site production for complex projects.

REFERENCES

[1] Winter, M., Smith C., Morris, P., and Cicmil, S. "Directions for future research in project management: The main findings of a UK government-funded research network," *International Journal of Project Management*, vol. 24, iss. 8, pp. 638-649, Nov. 2006.

[2] Francis, A. and Miresco, E., "Decision Support for Project Management Using a Chronographic Approach," in *Proc., 2nd Int. Conf. on Decision Making in Urban and Civil Engineering*, Lyon, France, 2000, pp. 845-856.

[3] Francis, A., Bibai, J., and Miresco, E. T., "Simulation of scheduling logic using dynamic functions," *Management, Procurement and Law*, vol. 166, iss. 3, pp. 145-158, June 2013.

[4] Malcolm, D. G., Roseboom, J. H., Clark, C. E., and Fazar, W., "Applications of a technique for research and development program evaluation," *Oper. Res.*, vol. 7, iss. 5, pp. 646-669, Oct. 1959.

[5] Eisner, H., "A generalized network approach to the planning and research and scheduling of the research program," *Oper. Res.*, vol. 10, iss. 1, pp. 115-125, Jan.-Feb. 1962.

[6] Pritsker, A. B., "GERT: Graphical evaluation and review technique," Memorandum RM-4973-NASA, Prepared for the National Aeronautics and Space Administration, The Rand Corporation, Santa Monica, CA: 138 pp., 1996.

[7] Crowston, W. B. and Thompson, G. L., "Decision CPM: A method for simultaneous planning, scheduling and control of projects," *Oper. Res.*, vol. 15, pp. 407-426, June 1967.

[8] Moeller, G. L. and Digman, L. A., "Operations planning with VERT," *Oper. Res*., vol. 29, iss. 4, pp. 676-697, Aug. 1981.

[9] Itakura, H. and Nishikawa, Y., "Fuzzy network technique for technological forecasting," *Fuzzy Sets Sys.*, vol. 14, iss. 2, pp. 99-113, Nov. 1984.

[10] Chehayeb, N. N. and AbouRizk, S. M., "Simulation-based scheduling with continuous activity relationships," *J. Constr. Engrg. and Mgmt.*, vol. 124, iss. 2, pp. 107-115, Mar. 1998, DOI: 10.1061/(ASCE)0733-9364.

[11] Martinez, J. C. and Ioannou, P. G., "State-based probabilistic scheduling using STROBOSCOPE's CPM add-on," in *Proc. Constructions Congress V*, Minneapolis, MN, ASCE, Reston, 1997, pp. 438-445.

[12] Francis, A. and Miresco, E. T., "A generalized time-scale network simulation using chronographic dynamics relation," In *Proc. Int. Workshop on Computing in Civil Engineering*, Miami, FL, ASCE, 2011, paper 114, pp. 560-568.

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