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A simulation approach for evaluating the impact of human behavior on project scheduling

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Abstract — *The increasing organizational complexity and competitiveness in the industry are driving interest in project management to ensure successful businesses. Uncertainty in estimating activities' duration is one of the main criticalities of the planning phase, especially in the industrial environment, where most projects, such as the optimization or qualification of new lines, usually require the involvement of resources whose commitment is almost never bound to just one task. In this context, the impact of human behavior if not properly considered can lead to serious damage in terms of time and costs and these hidden risks need to be properly assessed. The present study aims to analyze and quantify the impact of human behaviors (as described by Parkinson's Law, Student Syndrome, and hidden safety) on the project in terms of delays in scheduled time though the use of a Monte Carlo simulation. The objective of the methodology is to provide the project manager with the insight required to consciously address the uncertainties of the scheduling phase in order to ensure the success of the project. In order to illustrate the methodology in a more comprehensive way, a case study regarding a project for the innovation of the production process in a real industrial plant is provided.*

Keywords: Monte Carlo simulation; Student Syndrome; Parkinson's Law; hidden safety; PERT.

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1 INTRODUCTION

The competitiveness of the current global marketplace implies increasing importance for strategic planning in the industrial environment. The continuous evolution in technology and products drives the growing focus of organizations on the management of change and innovation in order to improve their own positions and adapt to the changeable global scenario [1]. Moreover, the capacity of innovating their own business is often linked to an organization's success. The ability to develop new products, plan new services, modify the production process flow, is vital in order to maintain and improve the market position. Indeed, change is not only an obligation but could also represent a competitive weapon when consciously directed. In this context, projects are the means to achieve the strategic goals of the organization [2].

The management of a project often presents difficulties. The inability to comply with the several competing constraints of the project usually translates into a failure of the project itself. The most typical causes for project failure are the inability to follow the schedule thus ending the project after the deadline, the excess of actual costs in relation to the planned budget and the nonconformity to specifications [3]. Therefore, time and resource management are key aspects in the definition of a project and the uncertainties and constraints influencing the project need to be handled by the project manager thought planning and control techniques [4].

This is especially true in the industrial environment, where being involved in several projects in a part-time manner is the norm. Projects such as the optimization or qualification of new lines, as well as the preparation for audits or the implementation of new standards, require the involvement of more resources, whose commitment is almost never bound to just that task. In this case, the uncertainty in estimating activities' duration represents one of the main criticalities of the planning phase. A failure in considering the impact of human behavior of the resources in this setting could lead to serious damage in terms of time and costs. The Project manager needs to carefully consider the hidden risks due to the impact of the behavior of the resources involved in the project.

The objective of this paper is to investigate and evaluate the impact of human behaviors (as described by Parkinson's Law and the Student Syndrome), showing their effects in terms of delays in scheduled time by the means of a Monte Carlo simulation. The method described to simulate and quantify the consequences of resources' performances on the schedule management will show in detail how the date of completion of the project could be seriously underestimated, in the absence of conscious risk mitigation strategies. The methodology aims to provide the project manager the insight necessary to tackle the uncertainties of the planning phase more consciously, thus enacting the appropriate countermeasures. In order to demonstrate the effects of the methodology in a more comprehensive way, a case study regarding a project for the innovation of the production process in a real industrial plant is provided.

The paper is structured as follows: Section 2 describes the background of the problem, discussing the impact of human behavior on project management and the different scheduling techniques available in the scientific literature. Section 3 provides a description of the method used to simulate the effects of human behavior on the project end while Section 4 shows the application of the described methodology to a real case study regarding the implementation of an innovation in the production process of a manufacturing company. Finally, Section 6 concludes the paper, presenting the main results and the possible developments of the study.

2 BACKGROUND

2.1 SCHEDULING TECHNIQUES

Scheduling improvement is one of the main issues that project managers have been focusing on from the dawning of Project Management, with the aim to plan, manage and control projects in a faster and more efficient way [5]. The application of management and control tools to project planning and scheduling allows to [6]:

- integrate effort and identify potential criticalities and slacks, preventing delays;
- evaluate the probability to accomplish objectives on time;
- highlight dangerous situations requiring management decisions;
- compare current expectations with scheduled completion dates and measure the probability to meet scheduled dates;
- simulate the effects of different alternatives in order to find the best solution.

In the last century, the specific topic of time scheduling has become increasingly important. Starting from assumptions of durations of deterministic nature, in the years first, the occurrence of uncertainties and later also the restrictions given by shared resources and capacities have been introduced [7].

To manage time from a project's management point of view network techniques are used. For each activity in the network, duration and precedence are defined in a deterministic or probabilistic way.

There main network techniques that consider network duration and precedence deterministic are CPM (Critical Path Method) and MPM (Metra Potential Method). The first is used with fixed durations and links of precedence, whereas the latter differs from it because it includes more types of relationship between the activities (namely, Start-to-Finish, Start-to-Start, Finish-to-Finish in addition to Finish-to-Start) [2].

Among network techniques that consider network duration and precedence not deterministic, PERT (Project Evaluation and Review Technique) is the most common. Developed during the Cold War by Lockheed Corporation of California for United States Navy and first introduced in “Polaris Project” and soon it became an extensively used planning tool in the business world, especially in U.S.A. [8].

The PERT can be defined as a programming and control technique which enables to schedule project completion date according to number and duration of activities to be carried out. Unlike CPM, PERT is a probabilistic tool that makes use of random variables and of their probability distribution to compute the probability of completion time [9]. In fact, by assuming a non-deterministic nature of activities, PERT provides an expected duration of the project (time limit within the probability of completion is 50%) while also describing the probability distribution of project completion [10],[11]. For each activity, the project manager and its team define the estimated duration depending on the situation of certainty, risk or uncertainty and then on the availability of evidence and data regarding the mode, range and distribution of duration estimates [12].

In literature, three different methods are proposed in order to estimate project duration: exact methods, approximating and bounding approaches and simulations methods. The first ones use techniques to find an exact solution [13]-[16] but results are often obtained under restrictive assumptions or for small networks. As a matter of fact, Hagstrom [17] has demonstrated how the Stochastic PERT Problem is in the class of #P-Complete problems and it is solvable only by exhaustive enumeration. The second methods determine upper/lower bounds to the distribution or its approximations. Since the accuracy of the estimates depends on the sample sizes, the costs in case of large networks computation enormously increase as accuracy needed heightens [18]-[21]. Finally, the simulation methods (such as Monte Carlo, also used in risk and cost management [22]-[23]) provide a valid approach to obtain statistics of mean and variance for any network with stated distribution by repeating consistent amount of iterations (e.g. a few thousand) [7],[24]-[26]. The definition of the likely duration of the activities requires the consideration of the probability distribution of duration [2] and considering the probability distribution of the duration of each project activity, PERT technique returns the probability distribution of project duration. In order to do so, three estimates are used to define an approximate range for an activity’s duration:

- Most likely: this estimate represents the duration based on the realistic expectations of the availability of the resources and their productivity;
- Optimistic: this estimate is the best-case scenario for the duration of the activity;
- Pessimistic: this estimate is the worst-case scenario for the duration of the activity.

The distributions most commonly used to describe the duration's distribution are the triangular and beta distributions [1].

Moreover, a simplified application of the PERT can be carried out using Beta distributions to estimate the expected duration of a project, thus allowing to obtain deterministic values that can be analyzed by CPM [27]. Other probabilistic network techniques are GERT (Graphical Evaluation and Review Technique: similar to the PERT but with precedence links expressed in a probabilistic way) and VERT (Venture Evaluation and Review Technique: a more complex technique which accounts time, cost, resources and risk variables contemporaneously) [2].

2.2 THE IMPACT OF HUMAN BEHAVIOUR

Growing interest is being addressed to the project performance problems in relation to the influence of the human side of project management [28]. The accurate estimation of tasks' duration is quite critical in time management and as the uncertainties concerning resource assignation increase when working on multiple projects or on a single project only part-time, the planning phase must minimize the risk of non-productive, ineffective, or misdirected effort [29]. The effect of human behavior on project performance is effectively represented by means of two paradigms, used to describe different effects caused by resource influences.

The first one is the Student Syndrome, as described in Goldratt's business novel [30]. The "Student Syndrome" is a term used to describe the phenomenon in which during the realization of an assigned task the resource shows irregular effort in its completion. Furthermore, the human agent in the allocated resource usually is forced to increase their effort as long as the tension develops, resulting often in a delay and causing considerable waste of well-intended contingencies [31]. Student Syndrome occurs more often when the team works in multitasking on different activities and, therefore, it is very frequent in the projects which tend to develop many modules in parallel. If just one module is affected by this behavior, the entire project can be late [32].

Another impacting human behavior is known as Parkinson's Law [33] which states that individuals tend to adapt their effort to the perceived level of difficulty and therefore the effort expands to fit the allotted time. Several authors have been studying the relationship between task difficulty, effort, and performance [34] but it was first articulated by Cyril Northcote Parkinson as a part of a humorous essay published in The Economist in 1955 [33],[35]. Indeed, only a few people force themselves to carry out work activities in the shortest time possible, instead unless a certain amount of stress is provided, the resources are not motivated to suppress their natural tendency to use all the time provided by the schedule to complete the task assigned [31]. Additionally, even task finished early by members of the team are not often declared as such, due to the tendency to improve or refine further the completed deliverable or to the desire to be considered a reliable estimator from the team (thus not contradicting their previous estimation) or to the fear of being granted less time in the future by declaring to have finished before the estimation. [36].

Furthermore, another typical problem in the scheduling process is the one known as “hidden safety”. It happens when people include, in addition to the real expected duration of their work, a time buffer for “safety”, in order to protect their forecasts. This buffer capacity is mainly related to uncertainties involved in performing activities, any distractions or interruption that may interfere, personal reasons (i.e. sickness, permissions, etc.) and, often, the allocation on several projects at the same time. This distortion is generally originated when, in the planning phase, the project manager does not ask for the time slot necessary to complete the activity (with the indication of a pessimistic, optimistic and most likely time) but instead he asks directly the date of completion. This may induce opportunistic behavior by the team members which, as stated beforehand, may declare an inflated estimation of the required time. Contrary to the other kinds of time buffers, placed by the project manager in order to control and recover risks, this one is not explicit but is “hidden”, since resources inflate their time estimates without disclosing and sharing the underlying motivations. Furthermore, the people being aware that their task could be achieved in less time, tend to also delay the start of the task, wasting the hidden safety before the task even begins [36]. Indeed, these phenomena are very common in project teams and represent major causes of time waste and delays since, if an unexpected problem comes from a task, the safety is lost, and the project overruns the estimate.

3 METHODOLOGY

In order to provide a way to estimate the effects of the impacting human behaviors on project time performance, a simulative approach is proposed.

The methodology is based on the implementation of a Monte Carlo Simulation and provides a way to model the different human behaviors previously described in the simulation environment, thus using the PERT not only as a scheduling tool but also as a time management method.

A comparison with and without the addition of human behavior in the analysis is carried out to illustrate how, if not taken into account, they can interfere with the completion date estimation.

Therefore, the discussion of the proposed method follows:

- Application and comparison of two approaches of PERT (simplified and by means of Monte Carlo simulation) to the simple project, using as inputs optimistic, pessimistic and most likely estimate for single task durations;
- Application of the Monte Carlo simulation modified to take into account the effects of human behaviors on task durations;
- Final comparison to analyze the impact of the differences introduced in the model.

3.1 SCHEDULING WITHOUT CONSIDERING IMPACTFUL HUMAN BEHAVIORS

While activity completion date can rarely be deterministic and is instead often affected by a certain grade of uncertainness, a common approach to its estimation is the use of Malcolm's method [37]. The method requires the assignment of the three estimates to each activity: optimistic (o), pessimistic (p) and the most likely estimate (m). Using this triad, the expected duration (or mean μ) and the standard deviation (σ) of activities' duration distribution [38]-[40] can be determined as follows:

$$\text{Expected Duration } (\mu) = (o + 4*m + p)/6 \quad (1)$$

$$\text{Standard Deviation } (\sigma) = (o - p)/6 \quad (2)$$

Considering as input, for each activity, the three duration estimates, the critical path can be easily determined by considering the sequence of activities-dependencies that determine the minimum possible duration of the project (the path with the maximum duration). In fact, the expected duration (ED) of a sequence of independent activities *i* is simply the sum of their own expected duration (central limit theorem):

$$\text{Project Expected Duration} = \sum\nolimits_{i=1\text{to } n(\text{critical path})} ED_i \quad (3)$$

On the basis of the critical path, the probability mass function of the overall duration of each time interval can be determined, taking as input its expected duration and its standard deviation, since the randomness in activities' durations justifies its form of a concrete probability distribution. Several known probability distributions have been proposed (i.e. triangular distribution [41], Poisson distribution [42] and normal distribution [43] but, considering the central limit theorem, the simplified PERT approach infers about project duration by approximating the probability distribution with the normal distribution [37]. Therefore, the standard deviation of the distribution (σ) can be calculated as:

$$\sigma = \mathrm{sqrt}(\Sigma_{i=1 \text{to } n}\, \sigma^2_i) \quad (4)$$

Where σ_i is the standard deviation of every single activity on the critical path.

Accepting the scheduled value as the project duration assures the completion of the project within that time just in 50% of cases. The use of a buffer sized as a multiple of the standard deviation of the distribution enables the increase of the probability of success within the date scheduled. Moreover, the evaluation of probability could always give an important insight to carry out trade-off analysis among benefits and penalties/revenue losses for delays and costs.

However, several discussions about simplified approaches point out the limits in focusing on a single critical path ignoring other paths. Indeed, given probabilistic activity durations [41]-[45], every path might have the potential to become critical [46], making the problem computationally intractable. In fact, it often leads to underestimating project duration [47] and this inherent optimistic bias can be referred to as the Jensen gap [47],[48] since it deals with Jensen's inequality.

In order to overcome this problem, it is possible to use both analytical methods [13],[16] and simulative ones. In particular, the Monte Carlo simulation method has been extensively used to sort out PERT problem [2] by finding an estimate of the completion time distribution as follows [49]:

- Determine for each activity the duration by choosing a random number from the activity duration distribution;
- Calculate the project completion date for this set of activity durations;
- Iterate the first two steps “n” times, counting the number of times “m” that project completion date ≤ given target time “t”.

Follows that the Monte Carlo simulation for the completion date distribution is equal to *m/n* (the cumulated probability to complete the project within the t target time).

In the simulation, the duration of each activity is modeled as a stochastic variable with an appropriate Beta function [2]. In statistics, Beta distributions are used to model the behavior of random variables in finite-length intervals and are applied extensively in PERT, CPM and other project management techniques to model events within an interval defined by an optimistic (minimum) and a pessimistic (maximum) value [37]. The assumption underlying this Monte Carlo simulation model is, therefore, that the duration of project activities is beta distributed with the density function:

$$f_{t(t)} = (t-\alpha)^{(\alpha-1)}/[(p - o)^{\alpha+\beta-1}B(\alpha,\beta)] \quad (5)$$

$$(p - t)^{(\beta-1)} \; o < t < p\alpha,\ \beta > 0 \quad (6)$$

The Beta distribution has four parameters (o, p, α and β), while PERT formulas of mean and variance just require the knowledge of three (o, m, p). In fact, Beta functions are parameterized by two positive shape parameters that can be calculated as follows [50]:

$$\text{Alpha } (\alpha) = [(\mu - o) / (p - o)] * \{[(\mu - o)*(p - \mu)/ \sigma^2]-1\} \quad (7)$$

$$\text{Beta } (\beta) = [(p - \mu)/(\mu - o)] * \alpha \quad (8)$$

The Monte Carlo simulation can be carried out through a common spreadsheet, using a number of iterations sufficient to guarantee accurate estimates. In fact, the activity duration can be simulated by computing the inverse of the beta with specified parameters alpha and beta, using the standard uniform random number generator for the probability, within the constraints of optimistic and pessimistic duration. Each output corresponds to the value whose cumulative probability under the Beta function defined by alpha and beta is specified by the corresponding probability; simulation results have statistics to converge to the theoretical values as the number of repetitions increase. Using this simulation approach, it is possible to define critical the path with a major percentage of criticality (the largest duration). Its definition can depend on the relationship between the standard deviation of the noncritical path (uncertainness) and their associated slack time or, more in general, on the common activities among different paths.

3.2 SIMULATION MODEL CONSIDERING IMPACTFUL HUMAN BEHAVIORS

After having carried out a simple scheduling process without considering the impact of human behavior, it is possible to make some modifications to the simulation to do so.

Different human behaviors can be modeled in the simulation in order to account for every possible circumstance, in particular, the three following behaviors are considered in the methodology proposed:

- Parkinson’s Law;
- Student Syndrome;
- Hidden safety.

The presence of hidden safety, as previously pointed out, is a consequence of the behavior of the project manager in the planning phase. By defining the activities' deadlines from the team estimates and so, unconsciously including hidden safeties in the schedule, the project manager interacts with the effects of Parkinson's Law and Student Syndrome, aggravating the situation further.

Adjusting work speed to the time available should not provide delays in an ideal condition where activity time is well estimated and there is an absence of risks. On the contrary, in reality, situations as the one described above are extremely rare; hence project managers and their teams, during project scheduling, must pay attention to Parkinson's Law effects since it can because of consistent delay. In order to simulate the effect of Parkinson's Law each activity's duration is set equal to the expected one even when it could be lower. This means that when the simulated activity duration calculated by computing randomly the inverse of the beta distribution function with specified parameters alpha and beta is lower than the expected one, the activity duration will be the Expected duration calculated through Equation 3.

Duration's activity with Parkinson's Law = max(Expected Duration (μ); Rand_AD) (9)

Where Rand_AD is the result of the random computation of the inverse of the Beta distribution function.

Moreover, also the effect of the hidden safety can be included in the simulation, replacing the expected duration of each activity with a different one, called "Duration with Hidden Safety". This duration can be calculated by computing the inverse of the beta distribution function using a specific value of probability for the distribution. For example, using a probability of 0.75 in the inverse function, it is possible to calculate a new duration for the activity that considers a hidden safety equal to the delay necessary to guarantee the termination of the activity itself with a 0.75 of success.

Considering the effects of both Parkinson's Law and hidden safety simultaneously is possible by comparing the result of computing randomly the inverse of the beta distribution function and the "Duration with Hidden Safety", instead of the expected duration, and choosing the greater value as the activity final duration.

Duration's activity with Parkinson's Law and Hidden Safety = max(DHS; Rand_Duration) (11)

Where Rand_Duration is the result of the random computation of the inverse of the Beta distribution function and SHS is the "Duration with Hidden Safety" (i.e. the activity's duration equal to the specific probability frequency with which the hidden safety is calculated (e.g. 0.75)).

On the other hand, Student Syndrome represents performance bias due to having more than enough time to accomplish a task. Its effect is simulated by delaying the start of each activity of a slot equal to the difference between the planned duration and the most likely estimate. This hypothesis is based on the assumption that the person is led to start working when he assumes to have enough time to complete the task, meaning a time span equal to the one considered most likely to finish it.

$$\text{Duration's activity with Student Syndrome} = \text{Rand\_Duration} + \text{SSDelay} \quad (12)$$

$$\text{SSDelay} = \text{Expected Duration } (\mu) - m \quad (13)$$

To consider all the mentioned effects together in the simulation, the delay provoked by the Student Syndrome is no longer calculated as the difference between the planned duration and the most likely estimate, but as the difference between the maximum between the result of the random computation of the inverse of the beta distribution function the “Duration with Hidden Safety” and the most likely estimate. Therefore, the equation for the Student Syndrome delay becomes:

$$\text{SSDelay} = \text{DHS} - m \quad (14)$$

4 CASE STUDY

The presented methodology has been applied to the case study of a manufacturing company in order to validate it, testing its usefulness and general applicability.

The company produces beer in drums, cans, and bottles. The production process involves several internal company areas: procurement (which deals with sourcing raw materials for the process and bottling), production (which takes care of the efficiency of the line), sales (which analyses the market demand), accounting, human resources, safety, maintenance, process quality, inventory management and internal and external logistics. Several external suppliers are involved in the supply of bottles, drums, and cans.

The increasing market demand has led the company to the decision of switching the supply of glass bottles from external to internal. Therefore, the project here described regards an innovation of the production process: the integration of a new production line for the autonomous production of glass bottles used in the original production process in order to stop obtaining them from an external supplier.

Table 1 reports the project activities, dependency relationships and duration’ estimates. The only type of relationship considered in this project is the “finish-to-start” one. For each activity, the three duration estimates can be used to evaluate the expected duration and the standard deviation as described in the previous section.

Table 1. Project activities, predecessors and duration’ estimates (in days), critical path definition and simulation input parameters

ID	Activity	Predecessor	Optimistic duration	Most Likely duration	Pessimistic duration	Expected duration	Standard Deviation	Alfa	Beta
1.1	Preliminary study of the new process	-	2.0	3.0	4.5	3.08	0.42	3.40	4.44
1.2	Preliminary study of the available floor	-	1.5	2.0	3.0	2.08	0.25	2.94	4.62
1.3	Downstream line demand analysis	-	8.0	10.0	13.0	10.17	0.83	3.40	4.44
1.4	New machinery requirements analysis	1.1;1.2;1.3	7.0	10.0	14.0	10.17	1.17	3.58	4.34
1.5	Optimal layout study	1.4	4.0	5.0	6.5	5.08	0.42	3.40	4.44
1.6	Analysis of internal logistic	1.5	5.5	7.0	9.0	7.08	0.58	3.58	4.34
2.1	Market research of new suppliers	1.6	25.0	30.0	37.0	30.33	2.00	3.51	4.38
2.2	Request estimates (machines)	2.1	8.0	9.0	11.0	9.17	0.50	2.94	4.62
2.3	Evaluation of estimates (machines)	2.2	4.0	4.5	5.5	4.58	0.25	2.94	4.62
2.4	Contract stipulation (machines)	2.3	4.0	5.0	6.5	5.08	0.42	3.40	4.44
2.5	Request estimates (internal handling)	2.1	8.0	10.0	13.0	10.17	0.83	3.40	4.44
2.6	Evaluation of estimates (internal handling)	2.5	4.0	5.0	6.5	5.08	0.42	3.40	4.44
2.7	Contract stipulation (internal handling)	2.6	4.0	5.0	6.5	5.08	0.42	3.40	4.44
3.1	Scheduling installation with suppliers	2.4;2.7	3.5	5.0	7.0	5.08	0.58	3.58	4.34
3.2	Installation supervision	3.1	28.0	30.0	34.0	30.33	1.00	2.94	4.62
3.3	Production lines' connection	3.2	6.0	7.0	9.0	7.17	0.50	2.94	4.62
3.4	Post-installation meetings with the Heads of the functions involved	3.3	3.0	4.0	6.0	4.17	0.50	2.94	4.62
4.1	First start of	3.4	2.0	3.0	4.5	3.08	0.42	3.40	4.44

	the line								
4.2	Operation process test	4.1;4.3	2.0	2.0	3.0	2.17	0.17	0.67	3.33
4.3	Contract closeout procedures	3.4	3.0	4.0	5.5	4.08	0.42	3.40	4.44
5.1	Performance control of individual elements of the new line	4.2;11.4	14.0	17.0	22.0	17.33	1.33	3.23	4.52
5.2	Waste management and rework management plan	5.1	12.0	15.0	19.0	15.17	1.17	3.58	4.34
5.3	Quality certification	5.2	5.5	7.0	9.0	7.08	0.58	3.58	4.34
6.1	System operation supervision	4.2	18.0	22.0	28.0	22.33	1.67	3.40	4.44
7.1	Analysis skills requirements for new workers	1.6	15.0	17.0	21.0	17.33	1.00	2.94	4.62
7.2	Curriculum analysis	7.1	6.0	7.0	9.0	7.17	0.50	2.94	4.62
7.3	Skills assessment	7.2	8.0	10.0	13.0	10.17	0.83	3.40	4.44
7.4	Contracts stipulations	7.3	1.5	2.0	3.0	2.08	0.25	2.94	4.62
8.1	Staff introductory meeting	7.4	7.0	9.0	12.0	9.17	0.83	3.40	4.44
9.1	Maintenance operators training	4.2	7.0	9.0	12.0	9.17	0.83	3.40	4.44
10.1	Analysis of the critical points of the line	4.2	50.0	60.0	72.0	60.33	3.67	3.74	4.22
10.2	Economic evaluation of faults	10.1	8.0	10.0	13.0	10.17	0.83	3.40	4.44
10.3	Failure frequency evaluation	10.2	52.0	60.0	70.0	60.33	3.00	3.68	4.27
10.4	Maintenance policy definition	10.3	18.0	20.0	23.0	20.17	0.83	3.40	4.44
10.5	Maintenance integration	10.4	14.0	18.0	23.0	18.17	1.50	3.68	4.27
10.6	Analysis of spare parts management process	10.5	9.0	10.0	12.0	10.17	0.50	2.94	4.62
11.1	Bottle supplier contract interruption procedures	1.6	5.5	7.0	10.0	7.25	0.75	2.94	4.62

11.2	New raw materials suppliers research	1.6	5.5	7.0	10.0	7.25	0.75	2.94	4.62
11.3	Potential suppliers' analysis	11.1;11.2	5.0	6.0	8.5	6.25	0.58	2.59	4.67
11.4	Contract stipulation	11.3	5.0	6.0	8.5	6.25	0.58	2.59	4.67
SIMPLIFIED METHOD Critical path:1.3 - 1.4 - 1.5 - 1.6 - 2.1 - 2.5 - 2.6 - 2.7 - 3.1 - 3.2 - 3.3 - 3.4 - 4.2 - 4.3 - 10.1 - 10.2 - 10.3 - 10.4 - 10.5 - 10.6. Completion date: 315.50 days Standard deviation: 5.99 days									
MONTE CARLO SIMULATION Completion date: 315.53 days Standard deviation: 5.99 days									

The simulation is achieved through 15000 trials in order to obtain accurate estimates.

The simulation shows that the path identified before as critical, in reality, as shown by the Monte Carlo simulation, is not always the actual critical path but only in just 84.8% of cases.

Figure 1 shows the probability distribution of scheduled values estimated with the simplified approach. In order to allow the comparison with the simplified method, the Gaussian curve of the simplified method is also depicted in the figure. As a matter of fact, the observed error is quite limited, especially if evaluated from a practical point of view and compared with the temporal uncertainties that there may affect the estimation of activities' duration.

This means that, despite the obvious theoretical limits in the application of the simplified method, in practice, its application can give useful insight into the planning phase.

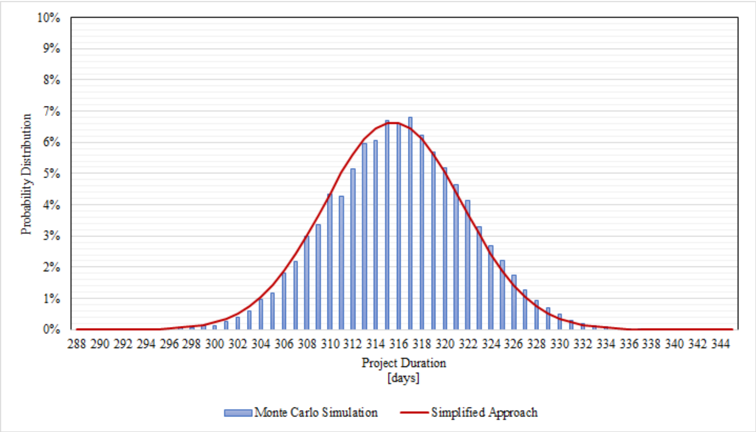


Figure 1. Simulation model compared to the simplified approach

Appling now the modifications described before to the simulation, it is possible to illustrate the effect of the human behaviors on the project's duration.

Four scenarios have been simulated to analyze the impactful behaviors and a final comprehensive overview is provided in the end:

- Scenario 1: Parkinson's Law effect;
- Scenario 2: Parkinson's Law and hidden safety effects (hidden safety equal to 75% probability);
- Scenario 3: Student Syndrome effect;
- Scenario 4: Student Syndrome, Parkinson's Law and hidden safety effects (hidden safety equal to 75% probability).

In order to enable the immediate interpretation of the simulation results, every simulation is compared with the curve of the normal distribution resulting from the application of the simplified approach.

4.1 SCENARIO 1: PARKINSON'S LAW EFFECT

Figure 2 shows the results of the first scenario, with only the effects of Parkinson's Law: the activities are not being declared as finished before the scheduled time reported in **Table 1** but can only be completed later or "on time", thus eliminating the probability in the left side of the curve.

As a consequence, the curve shifts from a Gaussian to a Beta distribution since the uncertainness moves forward.

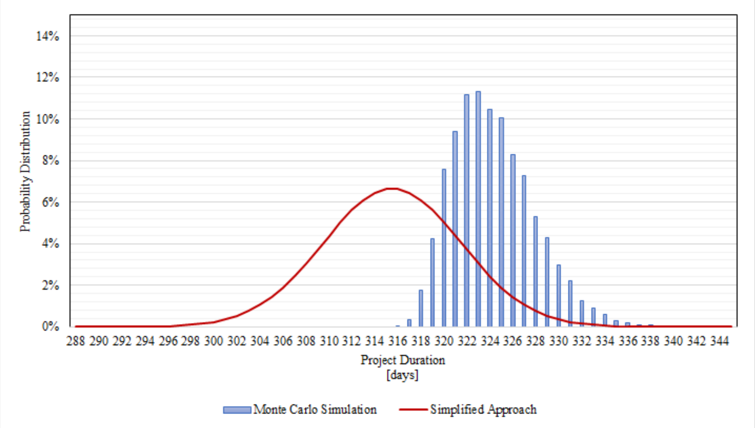


Figure 2. Parkinson's Law impacts on a simulation model

4.2 SCENARIO 2: PARKINSON'S LAW AND HIDDEN SAFETY EFFECTS

The second scenario of simulation adds the effect of the presence of a hidden safe in the scheduling of each activity to the Parkinson's Law effect. In this scenario, the project manager has not asked for the optimistic, most likely and pessimistic times but he has only asked for a simple estimation of the activity duration. Consequently, the estimations provided by the team were comprehensive of a hidden safety. The hidden safety considered for each activity is connected to a 75% probability of completion of the task. The choice of this specific value is meant to represent a realistic compromise (it is not so high to guarantee certain success, but the risk of failure is still reduced), highlighting the effects that even seemingly small delays can have in the scheduling process. Obviously this is just a parameter that can be adjusted in the simulation to better address the specific scenario examined. The consequently scheduled duration of the project changed from 315.5 days to 329.8 days.

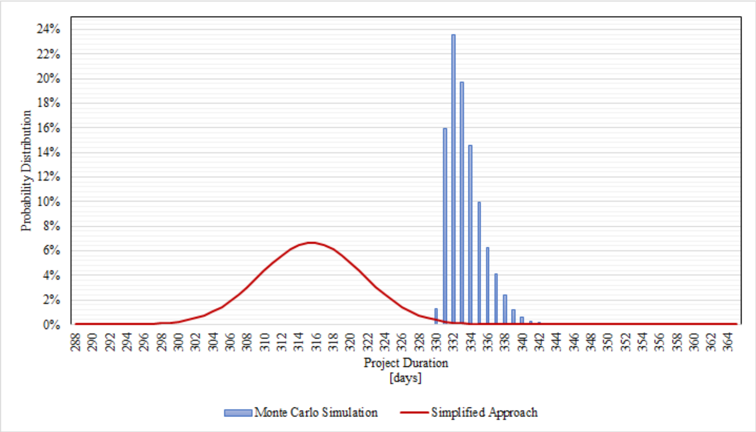


Figure 3. Hidden safety + Parkinson's Law impacts

4.3 SCENARIO 3: STUDENT SYNDROME EFFECT

Figure 3 shows the results of the influence of these two behaviors. The curve is still more similar to a Beta distribution because no activities are been declared finished before their scheduled time but there is also a shift to the right caused by the hidden safeties in the tasks.

The third scenario of simulation considers only the effect of Student Syndrome. As illustrated by **Figure 4**, planning on expected durations can partially address the problem of the Student Syndrome. Indeed, the result of the Monte Carlo simulation shows that the distribution kept its gaussian form and the effect is smaller than the one of previous behaviors.

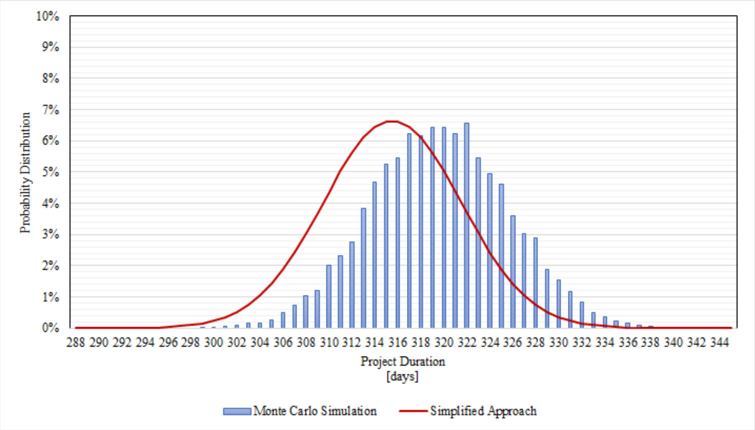


Figure 4. Student Syndrome impacts on a simulation model

4.4 SCENARIO 4: STUDENT SYNDROME, PARKINSON'S LAW AND HIDDEN SAFETY EFFECTS

Moreover, a comprehensive example of the simulation model is presented in the last scenario. The scenario shows the combined effects of all three behaviors: Student Syndrome, Parkinson's Law and considering a 75% hidden safety buffer on each activity. In this case, similarly to the second scenario, the scheduled duration has been affected by the different estimation techniques used by the project manager (simple value of duration asked the members instead of three different values to use in the PERT evaluation). **Table 2** provides the inputs for the Monte Carlo simulation.

Table 2. Human Behaviours inputs (in days) for the Monte Carlo simulation

ID	Optimistic duration	Most Likely duration	Pessimistic duration	Alfa	Beta	Hidden Safety	Delay
1.1	2.0	3.0	4.5	3.40	4.44	3.38	0.38
1.2	1.5	2.0	3.0	2.94	4.62	2.26	0.26
1.3	8.0	10.0	13.0	3.40	4.44	10.76	0.76
1.4	7.0	10.0	14.0	3.58	4.34	11.00	1.00
1.5	4.0	5.0	6.5	3.40	4.44	5.38	0.38
1.6	5.5	7.0	9.0	3.58	4.34	7.50	0.50
2.1	25.0	30.0	37.0	3.51	4.38	31.76	1.76
2.2	8.0	9.0	11.0	2.94	4.62	9.51	0.51
2.3	4.0	4.5	5.5	2.94	4.62	4.76	0.26
2.4	4.0	5.0	6.5	3.40	4.44	5.38	0.38
2.5	8.0	10.0	13.0	3.40	4.44	10.76	0.76
2.6	4.0	5.0	6.5	3.40	4.44	5.38	0.38
2.7	4.0	5.0	6.5	3.40	4.44	5.38	0.38
3.1	3.5	5.0	7.0	3.58	4.34	5.50	0.50

3.2	28.0	30.0	34.0	2.94	4.62	31.03	1.03
3.3	6.0	7.0	9.0	2.94	4.62	7.51	0.51
3.4	3.0	4.0	6.0	2.94	4.62	4.51	0.51
4.1	2.0	3.0	4.5	3.40	4.44	3.38	0.38
4.2	2.0	2.0	3.0	0.67	3.33	2.25	0.25
4.3	3.0	4.0	5.5	3.40	4.44	4.38	0.38
5.1	14.0	17.0	22.0	3.23	4.52	18.27	1.27
5.2	12.0	15.0	19.0	3.58	4.34	16.00	1.00
5.3	5.5	7.0	9.0	3.58	4.34	7.50	0.50
6.1	18.0	22.0	28.0	3.40	4.44	23.51	1.51
7.1	15.0	17.0	21.0	2.94	4.62	18.03	1.03
7.2	6.0	7.0	9.0	2.94	4.62	7.51	0.51
7.3	8.0	10.0	13.0	3.40	4.44	10.76	0.76
7.4	1.5	2.0	3.0	2.94	4.62	2.26	0.26
8.1	7.0	9.0	12.0	3.40	4.44	9.76	0.76
9.1	7.0	9.0	12.0	3.40	4.44	9.76	0.76
10.1	50.0	60.0	72.0	3.74	4.22	62.97	2.97
10.2	8.0	10.0	13.0	3.40	4.44	10.76	0.76
10.3	52.0	60.0	70.0	3.68	4.27	62.48	2.48
10.4	18.0	20.0	23.0	3.40	4.44	20.76	0.76
10.5	14.0	18.0	23.0	3.68	4.27	19.24	1.24
10.6	9.0	10.0	12.0	2.94	4.62	10.51	0.51
11.1	5.5	7.0	10.0	2.94	4.62	7.77	0.77
11.2	5.5	7.0	10.0	2.94	4.62	7.77	0.77
11.3	5.0	6.0	8.5	2.59	4.67	6.65	0.65
11.4	5.0	6.0	8.5	2.59	4.67	6.65	0.65

The combined effects of the three behaviors influenced more deeply the previous differences. Consequently, the gap between the simulation's and method of simplified Gaussian's results increases as shown in **Figure 5**.

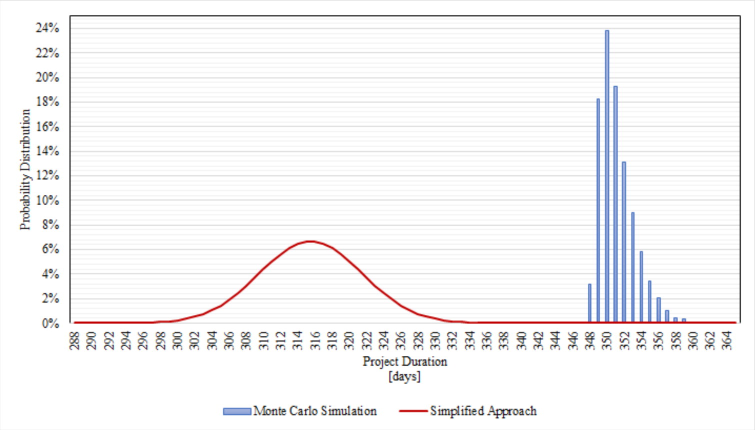


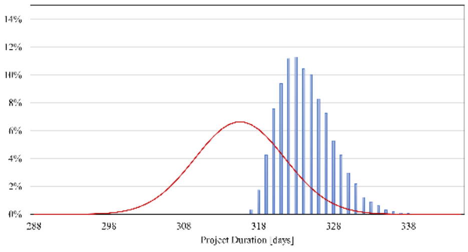
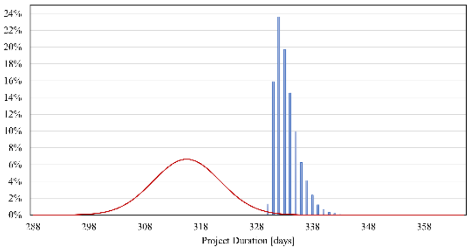
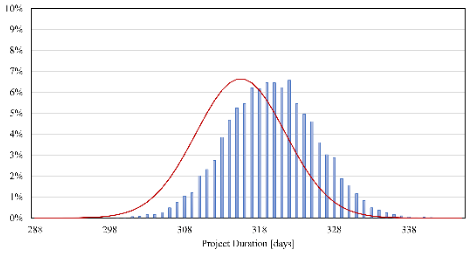
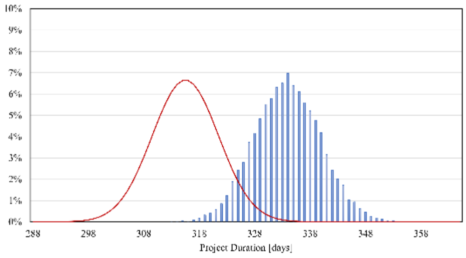
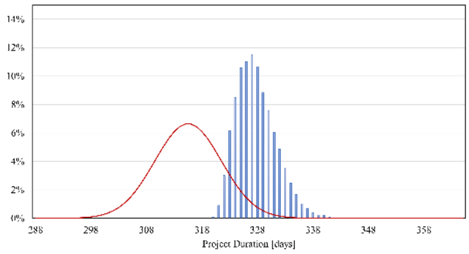
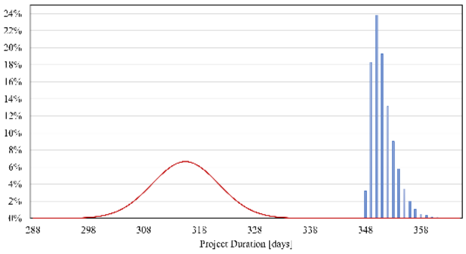
Figure 5. Human behaviors impact on a simulation model

The mean duration of the project calculated by the Monte Carlo simulation is 350.6 days. The value is quite different from the first one calculated without considering human effects and achievable also by using the simplified PERT, 315.5 days. Thus, the simulations showed how impactful human resources can be on the success of the project in terms of time.

Finally, **Figure 6** provides a synthetic and comprehensive overview of the effect of the different scheduling process and the different effects of human behavior on the duration of a project.

Indeed, the results of the simulations illustrate how critical the process of duration estimate can be for the success of the time management of the project. The use of the three-point estimate is fundamental for containing the human factor, lessening the impact of the different phenomena. In fact, even the use of a simplified approach for the estimation of the variance of the project duration allows us to quickly determine an adequate buffer to spend during the life of the project to ensure its completion.

Furthermore, the deeper knowledge of the potential effects that can be achieved by the methodology described in the paper can be useful to plan pre-emptive countermeasures. For example, this effect can be lessened if incentives based on early schedule performance are provided, in order to motivate team members.

	PLANNED ON EXPECTED DURATION	**PLANNED ON DURATION WITH HIDDEN SAFETY**
	DURATION WITHOUT HIDDEN SAFETY: 315.5 DAYS	**DURATION WITH HIDDEN SAFETY: 329.8 DAYS**
PARKINSON'S LAW		
	VARIATION MEAN COMPLETION DATE: + 2.6% STANDARD DEVIATION: – 40.5%	VARIATION MEAN COMPLETION DATE: + 5.5% STANDARD DEVIATION: – 65.6%
STUDENT SYNDROME		
	VARIATION MEAN COMPLETION DATE: + 1.2% STANDARD DEVIATION: – 0.3%	VARIATION MEAN COMPLETION DATE: + 5.7% STANDARD DEVIATION: – 0.9%
PARKINSON'S LAW + STUDENT SYNDROME		
	VARIATION MEAN COMPLETION DATE: + 3.7% STANDARD DEVIATION: – 41.0%	VARIATION MEAN COMPLETION DATE: + 11.1% STANDARD DEVIATION: – 65.6%

The effects of human behaviors are evaluated in terms of the variation of two statistical parameters resulting from the Monte Carlo simulation: mean completion date and standard deviation.

The variations are evaluated in each case by comparing the parameters with the ones obtained without considering the impact of human behaviors:

Mean Completion date: 315.5 days

Standard deviation: 5,99 days

Figure 6. Comprehensive overview of all possible effects of human behaviour on simulation model

5 CONCLUSIONS

The present paper presented a methodology to include the effects of human behavior in the scheduling process. In order to achieve this object, different models have been presented to consider the main human behaviors impactful on project time performance: Student Syndrome, Parkinson's law and hidden safety. The simulation approach has been tested on a real case study by the application of a Monte Carlo simulation.

The consequences of human behaviors have been studied in different scenarios analyzing their interactions and a comparison with the typical PERT application, both though the simplified method and the simulation approach, has been provided. Through the comparison of the shift in project completion caused by human behaviors, it has been illustrated how critical the effect of human behaviors can be if not taken into account when scheduling a project.

Indeed, as shown in the simulation, the human effects can induce a considerable sliding in project duration and can cause even further delays in the case of unplanned issues. This means that the project manager should be careful in the scheduling phase and should try to foster a climate of sharing so that the team members are more inclined to discuss clearly their difficulties with him and so that the plan can be shared and accepted by everyone. All this would have the dual advantage of making resources feel more responsible during the actual execution of the tasks and so limit the exacerbation of negative behaviors and, at the same time, give the project manager the possibility to plan more efficiently and therefore transparently manage temporal buffers in order to avoid unforeseen delays.

In addition, from a practical point of view, the proposed methodology can provide a tool for project managers to evaluate how human behaviors can possibly impact the schedule of the project. In this way, it is also possible to plan the best countermeasures to fight these effects.

Further extensions of the present work will consider adding the impacts of multitasking: in fact, while the unavailability of core resource, due to their allocation on multiple projects is generally considered in activities time estimates, rarely is taken into account the efficiency loss caused by resources which shift among different tasks. Further studies will also consider the consequences of the interactions present in a multi-project environment.

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