Controlling R&D Projects: Framing a Process

Micheli G.J.L.*, Soffientini L.*, Picutti B., Franzoni G.**, Bellini A.****

** Department of Management, Economics and Industrial Engineering, Politecnico di Milano, Piazza L. Da Vinci 32 20133 – Milano – Italy (Guido.Micheli@polimi.it, Lorenza.Soffientini@mail.polimi.it)*

*** Tecnimont S.p.A., Via Gaetano de Castillia 6a 20124 – Milano – Italy (B.Picutti@tecnimont.it, G.Franzoni@tecnimont.it, A.Bellini@tecnimont.it)*

Abstract: The purpose of the following paper is to increase the control reliability for R&D projects developed in Tecnimont S.p.A.. The control process should provide accurate results to allow the realistic description of project progress, and it is more complex when dealing with R&D projects: the uncertainty for some activities complicates the process of assigning variances and, consequently, the schedule becomes less robust. The proposal of a control process came after a careful study of previous literature about project control. A strong emphasis was given to the planning phase: as the schedule serves as a reference for control, Goldratt's Theory of Constraints – contaminated with elements from flexible methods and frameworks – is adopted to guarantee the baseline a stronger adherence to reality. The schedule higher adherence to reality was validated coupling the interview and the what-if methodology; these provided, respectively, a qualitative and quantitative proof of the effectiveness of the proposed control process. This control process appears to be reliant on a schedule that is more adherent to the events that can occur in reality. The higher accuracy of the schedule allows knowing more accurately which is the level of completeness of the project. By this means, it is sufficient to adopt a simple metric for project control instead of more complex algorithms (which are not always used in the industrial reality). Differently from some approaches such as stochastic and fuzzy logic, the control process is presented as a simple and pragmatic solution that can be adopted for R&D projects aimed at the development of industrial technology, including the construction of a pilot plant and the execution of experimental campaigns.

Keywords: Project Control, R&D management, Theory of Constraints, Flexible Framework and Methods, R&D projects.

1. Introduction

The focus of the present paper is on those R&D projects whose objective is validating a new technology and verifying its potential applicability on an industrial scale. Such validations may include the construction of pilot plants and the execution of experimental campaigns. R&D projects have some peculiar characteristics that differentiate them from non-R&D ones: the first are by their nature high-risk projects with many unknowns and great technical uncertainties (Cooper, 2007). The risk factors that affect R&D projects the most is the degree of unfamiliarity and the lack of experience concerning certain design conditions (Dey, Tabucanon and Ogunlana, 1994).

The case studies examined in this paper refer to the R&D projects developed in a large EPC (Engineering Procurement & Construction) firm where project management and project control are every day's tools. Tecnimont S.p.A, an international leader in the field of Engineering, Procurement & Construction of large-scale projects worldwide mainly in petrochemical, fertilizers, oil & gas, refining and power plants, is a subsidiary of Maire Tecnimont S.p.A., a technology-driven multinational Group working for the transformation of natural resources into innovative products.

Typically, in the context of large EPC firms, R&D projects represent a small share of effort in the company's development portfolio (Cooper, 2007) but they are vital to the company's long-term growth, prosperity and sometimes even survival (Kivisaari, 1991; Cooper, 2007). Besides the consideration that R&D projects are one of the primary ways to acquire knowledge, they enhance innovativeness (Cuervo-Cazurra, Nieto and Rodríguez, 2018), play a predominant role in improving the competitiveness of firms (Gunasekaran, 1997) and shorten the response times to capture opportunities (Gunasekaran, 1997; Wang *et al.*, 2018).

Seen the relevance of the R&D project outcomes, it appears that adequate project management tools and techniques are necessary to maximize the success probability of these projects. Some authors believe that the application of traditional management techniques to non-traditional projects may not be adequate (Cooper, 2007), others believe that current methods should take into consideration R&D projects peculiarities by extending and integrating other existing methods (Cassanelli and Guiridlian Guarino, 2014), others again believe that more importance should be given to some tools such as risk analysis (Wang *et al.*, 2018) for example, during the planning phase (Dey, Tabucanon and Ogunlana, 1994); hence many researchers are studying on the mitigation strategies of the schedule risks in the project management (Zhang and Yang, 2014). In this article, the attention will be focused particularly on project control, the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organization's objectives (RN, 1965). The aim of the paper, hence, is providing a control process which enables industrial Project Managers to track the degree of completion and progress with a certain level of robustness and reliability for R&D projects. Project control includes the set of activities and tools used to verify whether the project proceeds according to the time and costs trends forecasted. It also allows to make predictions about future trends and to select the best strategies to allocate resources or – whenever a deviation is present – to apply corrective actions. It has been suggested that an organization undertaking several projects should adopt a common project management approach for all projects in the program, regardless of the type of project, its size, or the type of resource used (Turner, 1988); advantages are reported in Turner et al. (1999) (H Payne and Rodney Turner, 1999). On the basis of the results of a survey submitted to management people (H Payne and Rodney Turner, 1999), the use of procedures regardless of project peculiarities is less successful compared when the procedures were tailored to the project, hence a customized control process is proposed. The construction of an accurate baseline implicitly turns into a more realistic estimate also of the project budget which could discriminate a project undertaking: an inaccurate budget evaluation can discard the possibility of undertaking a new project with all the related consequences outlined before. Project control is strictly bound to planning (Omta, Bouter and Van Engelen, 1994): only by constructing a reference (baseline), it is possible to compare real trends with planned ones. Planning methodologies were largely studied for those projects related to consolidated technologies where a lot of recorded historical data are available, but the same cannot be said for Research and Development (R&D) projects (Golenko-Ginzburg, Gonik and Kesler, 1996). Besides the lack of historical data and technological uncertainties, estimating activities duration for R&D projects is not straight forward. Similarly, there are uncertainties related to the lack of experience about the technology and the technical solutions for the process. It follows that R&D projects should be carried out with a kind of "creativity", making some non-conventional choices (Wingate, 2014).

To face the problems related to the baseline construction, it must be reported that several approaches have been studied and adopted. Literature offers many examples of models for variance computation by probability-based or fuzzy set-based methods (Weglarz, 1999; Cooper, 2007): the first way to proceed is associating a probability distribution function to the unknown variable; for fuzzy set-based methods, fuzzy logic is used and its reliability can be improved by experts' judgment and project managers' experience (Long and Ohsato, 2008).

Academics, companies' specialists and managers can benefit from the results of this study which provides a control process that can suit the R&D project characteristics previously mentioned. Uncertainties can be better managed, and corrective actions can be more focused and efficient.

2. Literature Review

A wide number of studies and researches concerning the calculation of activities parameters are offered by literature but a little investigation has been undertaken in the area of planning and control of R&D projects (Ouchi, 1979; Golenko-Ginzburg, Gonik and Kesler, 1996).

Historical developments of the last years of 1900 showed the need to develop methods and frameworks that could better adapt to new project characteristics (Wingate, 2014), requiring speed in taking decisions and related to innovations. Flexible methods and frameworks – originally born, and still mainly used for the software field – represented the new approach to manage R&D projects. To mention the most known, Spiral Development, Agile Method and Scrum method share some common points: iteration is the key feature to add value to the product and to solve any new problem encountered along the way. Flexible methods and frameworks are more focused on getting the added value as soon as possible: to do that, activities are not detailed straight at the beginning of the project, many loops are introduced, and a lot of importance is given to the project team and the communication between each other. It is the authors' opinion that the application of the flexible methods and framework shows some limitations and is not applicable straight forward to plant construction projects: flexibles characteristics better suit the field where innovation is meant as incrementation of features or in contexts where modifications can be easily applied. Despite existing flexible methods and frameworks, R&D projects are tried to be controlled using deterministic techniques (Golenko-Ginzburg, Gonik and Kesler, 1996): an example is provided by Tecnimont. The Company chooses, as many others, the Earned Value Management method (EVM) as a control method, which has been proven itself to be one of the most effective performance measurement and feedback tools for managing projects (Institute, 2011). The progress is measured by comparing the planned work executed with the one which is not accomplished yet. Afterward, some performance indicators are computed which allows the computation of the project performance and to make forecasts about future project behaviour. The application of EVM is usually successful when a detailed Work Breakdown Structure (WBS) is adopted: taking Tecnimont as best practice EPC contractor, the WBS is used to integrate all the project information, to organize and define the project scope into sub-activities that are ordered hierarchically and assigned a time and cost. Given that R&D projects brings many uncertainties about timing, costs (but also about the effectiveness of some activities), the application of EVM does not guarantee with the same confidence a good result.

Many examples of stochastic methods are offered in the literature (Acebes *et al.*, 2015) to estimate time and cost variance. Although the related simulations allow the modelling of multiple scenarios covering customized range for the variable values, the strongest limitation is the confidence that the project manager can associate to probability distribution functions: for R&D projects, the lack of historical data and records in databases could lead the project manager to characterize incorrectly the random variables (Dodin, 2006). Fuzzy set-based methods provide viable alternatives in the R&D environment but, even if they have been proposed for many project scheduling (Chanas and Kamburowski, 1981; Lootsma, 1989; Lorterapong and Moselhi, 1996; Bonnal, Gourc and Lacoste, 2004; Long and Ohsato, 2006, 2008), however, it seems that they are not currently applied in many industry fields.

Gunasekaran (1997) (Dey, Tabucanon and Ogunlana, 1994) points out that a simplified process control to be applied R&D projects turns out to be inadequate: hence, the need to tune a different control process, based on proven management standards and integrated with appropriate methodologies, suitable for R&D projects (Cassanelli and Guiridlian Guarino, 2014).

3. The proposed control process

The proposed control process, that is inspired either by flexible methods and frameworks, and by Goldratt's Theory of Constraints (TOC), is focused on the planning.

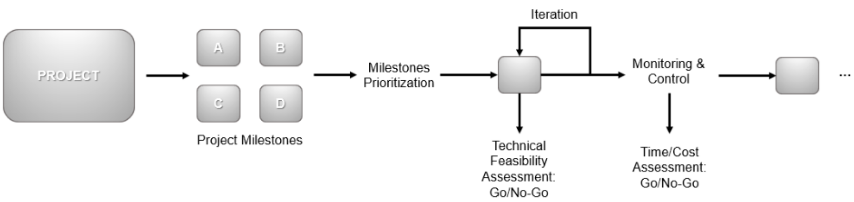
Planning has a strong interface with control: it is essential to define project objectives and requirements and, therefore, is the basis for reliable project control (Kerzner, 2017). If the planning accuracy is higher, so is the probability to perform a more effective control. The proposed process is shown in Fig.1.

by producing discrepancies with respect to what was originally planned.

It is therefore of paramount importance to early identify these events and outline possible solutions to be implemented to mitigate their effects on the overall performance: for this reason, the project should be organized in identifiable milestones (A, B, C, D). These milestones should be prioritized according to their level of uncertainty and associated to a buffer. Differently from TOC, to provide for the inaccuracy of statistical forecasts, buffers consider technical, mechanical and process uncertainties in a measure which is not typically considered in non-R&D projects (poor performance of a piece of equipment, conceptual and theoretical errors, etc.). For each activity characterized by uncertainty, the magnitude of the risk can be computed, and risk analysis allows the prioritization of these activities. Differently from TOC method, for the proposed control process, a dedicated buffer is directly associated with any activity characterized by important uncertainty. For each of these activities, the capacity of the buffer is computed based on the magnitude of the risk. Each buffer can be exploited for the implementation of possible recovery/mitigation actions up to the finalization of a suitable solution (iteration) should an adverse event occur. The iteration phase also enables the project manager to learn about the technical feasibility of the project.

In addition, based on the results of the risk analysis, the original project schedule is re-modelled to anticipate, whenever possible, the activities characterized by high risk.

Figure 1: The control process proposal



The traditional application of TOC requires the prioritization of the *constraints*, that are usually all the most complex and difficult activities that are hard to be exactly characterized in time, effort and costs; all these uncertainties are managed through the introduction of buffers positioned at the end of the critical path and at the end of sequences of activities influencing the critical path. Constraints buffers are then computed based on activities variances taken from databases and statistical methods. The application of TOC is doubted to be successful if applied straight forward to projects with a high level of uncertainty: activities times, efforts and costs cannot be estimated because there is no previous reference. In addition, there is no certainty about the final result (which is usually assured for well-known processes) or, for example, about the real functioning of a new piece of equipment. During R&D projects execution, the adherence and accurateness of the control metric are likely to fail in case of the occurrence of unforeseeable events/changes. These events are known as project creeps, i.e., circumstances that affect the schedule

In such a way, for any uncertain event, a timely decision about whether to continue with the execution of the project or to leave it can be taken (go/no-go) based on the efficacy of the mitigative actions that have been tried.

The distribution along with the schedule of these buffers, associated with the possible anticipation of high-risk activities, enables better control of the project. If an adverse event occurs and none of all the identified mitigative actions is effective, the decision to leave the project can be timely taken; on the other hand, if the mitigation action is effective, the project will progress; the presence of the buffer (that has been used for the implementation of the mitigating action) prevents the introduction of further delays in the planned schedule and makes easier to control the project.

4. Theoretical validation

The theoretical validation of the process for control was performed by consulting three senior managers of Maire Tecnimont Group involved in R&D projects (the "project managers" as henceforth indicated). Robustness and completeness were tested adopting the "interview" methodology: by this means, all the interviewed managers evaluated the control process referring to their experience in past and ongoing R&D projects.

The validity of interviews is based on the assumption that interviewees are competent and truth-tellers (Qu and Dumay, 2011). Interviews consisted of structured conversations (Jamshed, no date; Gillham, 2000) aimed at collecting information and project managers' points of view on the control process proposed. The selected sample of people that was submitted with the interview was not so numerous (three people): this is because – in Maire Tecnimont Group – there are only little examples of R&D projects with the characteristics described in the Introduction. The interview re-elaborations were submitted to interviewees to check the content consistency and correctness.

Interviews were oriented to collect the project managers' opinions and experiences about the salient features of the proposed control process, namely uncertainties, risks and the choice of control metrics. As expected, there is a wide convergence on the themes discussed, validating the process theoretically. All interviewed judged the risk analysis as an important step that does not add substantial costs to the planning phases. Considering the level of uncertainty characterizing R&D projects, all the respondents share the conviction that re-planning (using, for example, the Rolling Wave Breakdown Structure) is a useful tool that can be used to update the baseline as well as the anticipation of the testing phase of some units and components. Finally, all project managers share the idea that focusing on improving the accurateness of the baseline (for example considering some time to be devoted to iteration and testing) makes also simpler metric effective in controlling the project.

5. Quantitative validation

The proposed control process accuracy and adherence to reality were challenged to be better than the control process applied in an industrial example of an R&D project. Through a what-if analysis, a new project schedule (project W) was produced accordingly to the control process proposal; process performances are successively compared.

To tune the Control Process proposed before, a "what-if analysis" was used: it is a simulation whose goal is to inspect the behaviour of a complex system (i.e., the enterprise business or a part of it) under some given hypotheses (Golfarelli, Rizzi and Proli, 2006). This methodology has already been applied for the validation of simulation models (Golfarelli, Rizzi and Proli, 2006). As done by Chen et al. (2014) and Andrade et al. (2018) (Chen, 2014; de Andrade, Martens and Vanhoucke, 2018), accuracy for each node was computed using the Mean Absolute Percentage Error (MAPE). It is defined as:

$$MAPE = \frac{100}{n} \sum_{n=1}^{n} \left| \frac{\widehat{y_t} - y_t}{y_t} \right|$$

where y_t is the actual value for time t to perform an activity or a set of activities; $\widehat{y_t}$ is the predicted value for y_t to perform an activity or a set of activities; n is the number of phases to which is related to the computation for accuracy. As accuracy will be computed considering single phases for a single project, n assumes the unitary value.

5.1 Case study

An R&D project developed in Tecnimont S.p.A was chosen to quantitatively assess the features of the proposed control process. The scope of work included the design and construction of a laboratory-scale pilot plant (sited in Piacenza area, Italy) and the execution of two experimental campaigns for the validation of the process. The pilot plant was built to validate a new technology for natural gas sweetening – which is typically contaminated with carbon dioxide – through an innovative scheme of cryogenic distillation. The project had also the goal to verify if the innovative technology had the characteristics to be applied on the industrial scale The project included the development of the detailed design, the pilot plant physical construction, and the execution of the first experimental campaign. Whenever the first campaign had not provided sufficient and exhaustive data to validate or confute the theory at the basis of the proposed process, the chance of running a second experimental campaign was taken into account. For the sake of the following discussion, R is the real project and W is the what-if project. Both types of projects were compared in Tab. 1 and Tab. 2 based on their original schedule (the one built before the project started) and the actual schedule (which represents the effective development of events occurred – or thought to occur for project W).

Project R data were taken for the real project documents. For what concerns project W, the original schedule was assembled mainly referring to project R activities durations:

- one day is assigned to the prioritization phase (which includes a qualitative risk analysis and the reorganization of activities precedence). This amount of time was established following the experts' opinions;
- construction is planned to be three months longer as the pilot plant vendor was proved to be able to provide the accurate estimation of the delay caused by the decision to test some unit functionality;
- once construction is concluded, a new planning ad risk analysis session is done in project W: here the plant is assumed to be the element to be tested and iterated before the experimental campaign starts. One day is assigned to this planning session;
- the experimental campaign is unique because plant tuning is meant as a testing phase for the plant functionality. Only after the plant is declared to be operative and stable experiments can start;
- in addition to the time used for tests, four months are added for one of the pumps troubleshooting. Since at the early stage of risk evaluation it is not always clear which could have been the specific problem affecting the pilot plant, general considerations are done: the process pump had already been detected as a potential criticality for the project so – to be conservative – the complete failure of the pump is considered to compute the amount of time to be added to ordinal activities. According to qualified pump constructors, pumps that are likely to suit the

project purposes are built in three or four months: as the success of a brand-new pump is not assured, four months are taken as timespan. In this way, it is accounted for any further iteration to solve the pump instability;

- for what concerns the experiments, the duration of the single campaign was assumed to be equal to project R's *2nd Experimental Campaign* – which was performed once the plant was proved to be stable.

Campaign, the experimental phase is assumed to last as project R's actual *2nd Experimental Campaign*.

5.2 Results and content analysis

For what concerns accuracy evaluation, MAPE was expected to demonstrate that the "what-if" project is more accurate than project R; in fact, the project W schedule was widened because of the introduction of tests on the pilot

Table 2: **data for project R, planned and actual schedules**

Phases	Planned start date	Actual start date	Planned end date	Actual end date	Planned duration in calendar days	Actual duration in calendar days
Detailed design, planning of operations	19-02-15	19-02-15	15-04-15	15-04-15	56	56
Construction	16-04-15	16-04-15	19-11-15	06-03-16	219	329
Handover	20-11-15	07-03-16	30-01-16	18-05-16	73	73
Tuning	01-02-16	19-05-16	25-03-16	23-09-16	53	130
1st Experimental campaign	26-03-16	24-09-16	02-12-16	31-05-17	251	251
Analysis of 1st exp. camp. results	03-12-16	01-06-17	01-02-17	31-07-17	62	62
Pilot plant revamping	-	01-08-17	-	28-11-17	0	121
2nd Experimental campaign	02-02-17	29-11-17	27-11-17	30-10-18	300	337
TOTAL					**1014days, 34months**	**1359days, 45months**

Table 1: **data for project W, planned and actual schedules**

Phases	Planned start date	Actual start date	Planned end date	Actual end date	Planned duration in calendar days	Actual duration in calendar days
Detailed design, planning of operations	19-02-15	19-02-15	16-04-15	16-04-15	57	57
Construction	17-04-15	17-04-15	21-02-16	07-03-16	312	329
Handover	22-02-16	08-03-16	05-05-16	20-05-16	74	74
Tuning	06-03-16	21-05-16	28-10-16	13-03-17	177	298
Experimental campaign	29-10-16	14-03-17	23-08-17	12-02-18	300	337
Analysis of exp. camp. results	24-08-17	13-02-18	23-10-18	15-04-18	62	62
TOTAL					**982days, 32months**	**1157days, 38months**

The real project lasted more than expected due to the occurrence of unexpected adverse events that enlarged the scope of the project: major modifications were applied to the pilot plant to improve its operative conditions and a second experimental campaign was performed. Project R data were taken for the real project documents.

Project W actual schedule was modelled on the considerations made for its original schedule and considering the actual times of project R. Days devoted to project W actual *Plant Tuning* are increased because, to guarantee the plant efficiency obtained for project R *2nd Experimental Campaign*, a revamping must be included (121 additional days). Finally, since the number of project W's experiments is equal to project R's *2nd Experimental*

plant and of the elongation of troubleshooting times: a longer duration better resembles the actual project development. Start and End dates are included in the computation of timespans. As it is dealt with time extensions, calendar days are considered. For project R's actual *Experimental Campaign*, the *1st* and the *2nd Campaign* days are summed to represent the effective number of days needed for the technology validation. The *Plant Modification* sections include the days devoted to *Plant Tuning* and the revamping. In Tab. 3, values for MAPE are reported.

The proposed control forecasts result in being more or equally accurate than the real project ones in most of the cases. Colin (1982) (Colin David Lewis, 1982) allows the interpretation of the results obtained; for a MAPE<10, a forecast is highly accurate. This result was obtained the project phases which were related to project planning: hence, planning is less likely to accumulate delay because there is not the chance to physically verify if planned technical solutions are effective once constructed and installed.

Table 3: results for MAPE computation

Phases	R: $\hat{y}_t$	R: y_t	MAPE R	W: $\hat{y}_t$	W: y_t	MAPE W
Detailed design, planning of operations	56	56	0	57	57	0
Construction	219	329	33,43	312	329	5,17
Handover	73	73	0	74	74	0
Pilot Plant Modifications	53	251	78,88	177	298	40,60
Experimental Campaigns	551	588	6,29	300	337	10,98

In project R *Construction*, *Plant Modifications* and *Experimental Campaigns* were subjected to deviations which complicated the progress measure. The best improvement can be observed for the construction phase because it is assumed that the expert and qualified pilot plant vendor can envisage how much time has to be devoted to, doing specific tests on units (which corresponds to reality). As far as *Plant Tuning* is concerned, it is very complex to know in advance which could be the specific problem/s affecting the plant reliability: only the exact knowledge about the technical anomaly enables the project manager to consider possible corrective actions and their temporal quantification.

Only the results related to *Experimental Campaigns* suggests that project R forecasts are more accurate than project W's. This trend can be explained by the fact that, in this analysis, the days related to both projects' *Experimental Campaigns* have been added up. As already highlighted, the possibility to perform project R's *2nd Experimental Campaign* was considered in the original planning but represents an extension of the original work scope. Project R's *2nd Experimental Campaign* execution can be assumed to be an alternative way to iterate the *1st Experimental Campaign* and, due to this, its consideration for MAPE computation improves the index value. Nevertheless, if project R's *2nd Experimental Campaign* was not used in the computation, the MAPE index would result in being equal to 53,31, which is a more unsatisfactory result than project W's. Anyway, although project R shows a better result for the *Experimental Campaign*s, this does not compensate for the worse results obtained for the other phases analysed. These considerations demonstrate that the iterative planning and tasks execution should be incentivized – which is a concept strongly supported in the control process proposal. According to the results, it can be stated that the process introduced improves forecasts accuracy and, consequently, the overall control process is improved.

6. Conclusions

In previous sections, three R&D projects were described and analysed. Their characteristics make their control process peculiar and, although in the last years of twentieth-century (Beck *et al.*, 2001; Wingate, 2014) the introduction of flexible methods and frameworks has strongly changed the way to manage new typologies of projects they cannot, however, be applied straight forward to projects that include in their scope the construction of a pilot plant and the subsequent execution of experimental campaigns. In the present work, it is assumed that the difficulties related to control R&D projects are, essentially, in the planning phase, that is made more complex by the project uncertainties. Although literature offers a good number of examples and attempts to model such uncertainties with stochastic methods (Long and Ohsato, 2008; Bruni *et al.*, 2011; Acebes *et al.*, 2015; Bistline, 2016; Hazır and Ulusoy, 2019), they cannot provide accurate result since the simulations are run with inaccurate data. The control process is proposed as a practical solution for companies dealing with R&D projects. This guarantees the applicability of the results also to R&D projects different from the one subject of this discussion. The project that has been analysed in detail, was managed following a logic similar to the proposed control process: although the original planning did not include the early technical tests here above described, however, they have been timely carried out to avoid major disruptions in the schedule. Also, the key role of technical experts able to identify the tests to be included in the original schedule should be underlined. The proposed process shows, however, some limitations. The timespan for testing and iteration is quantified with a conservative approach which does not exclude that the timespan allocated for a specific activity exceeds the actual amount of time needed: in this case the project time advantage could be lost. Although re-scheduling can be done, however, for project activities characterized by scarce flexibility, the benefits are negligible. Due to this limitation, a deeper study of methods to estimate the duration of iterations could be carried out. Possible methods to be pursued could be the fuzzy-based ones: this solution could compromise the easy application of the control process but would likely improve the quality of the buffer extension. Another aspect worthy of further investigation is the choice of the control metric. Although in this paper the major problem was assumed to be the baseline strong deviation from reality, it cannot be excluded a priori that some metrics could provide more detailed and accurate information about the project progress. Finally, keeping into account the continuous developments and changes occurring worldwide, it is fair to think that the impact of these variations would be observed also at the project level: environmental circumstances and constraints could induce new needs; thus, in a next future also non-R&D projects may be managed differently. In this sense, the control proposal described in the present discussion represents an innovative process that could be tested also on non-R&D projects.

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