An application of Project Management techniques for the estimation of processing times in industrial projects with a high degree of innovation

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Abstract: During the last few years, both industrial and academic people have questioned the usefulness of Project Management (PM) tools in manufacturing field. Despite several applications arising from PM now known like time management, risk management, budgeting, scheduling and others, these tools appear to be barely used where industrial projects are characterized by a high degree of innovation. Throughout history the great uncertainty about innovative projects duration obliged project managers to overestimate processing time as precautionary behaviour. This conduct often precludes new project opportunities for companies, decreasing their competitiveness. To overcome this limit, this work wants to develop a hybrid methodology to estimate as accurately as possible individual durations of activities belonging to a complex process. That kind of intervention lead to minimize possible costs for wrong estimations and maximize enterprises competitiveness. For this purpose, the authors combine some statistical tools used in Project management as Program Evaluation and Review Technique (PERT), Critical Path Method (CPM) and the parametric estimation with physical models used in manufacturing field, validating the obtained results in a real manufacturing case study. Through this research, authors put in evidence the possibility to adopt these techniques to well-known procedures employed to make products never realized before, for which no previous accurate data are available so far. This study highlights how it would be possible to reduce the effect of precautionary behaviors, supporting companies to accept a higher number of projects to be developed in a time range.

Keywords: Project Management technique, Time estimation, Industrial Project

1. Introduction

Competitiveness is a crucial aspect in the new industrial paradigm. It depends on many important factors including the readiness toward new innovative projects and productions. Project Management (PM) aims to plan, manage and control projects basing on a triple constraint concerning respect of duration, costs limits and quality level. These constraints are also known as "iron triangle" (De Wit, 1988). These aspects are equally important during project development phase but it is quite difficult to consider all three at the same time. For new projects, especially when the product is innovative or never done before, it is not easy to establish resources and estimate costs and activities durations. Starting from these statements, in this work we want to pay more attention on activities duration estimation on which the other two aspects also depend.

Today's technical and technological competition leads management to adopt methods and software to forecast as well as possible projects duration and maintain all the activities under control avoiding possible delays. As the products degree of innovation grows, also complexity, given by the increasing number of variables, grows. For this reason, new solutions and new applications are needed to increase enterprise competitiveness. In such a scenario, the role of project manager is to interpret the situation in terms of risks and uncertainty and then estimate a duration distribution (Hershauer and Nabielsky, 1972). He has to consider all the variables influencing all activities and decide which of them are more or less important for improving companies competitiveness (Uzzafer, 2013).

Time Management (TM) is the PM field whose objective is to optimize the activities belonging to a project in such a way as to respect time opportunities or constraints. According to (Westland, 2007), TM is the process of recording and controlling time spent on a project. More in general, TM is composed by several methodologies and techniques designed to fix and respect a deadline. It includes a wide range of operations as well as: planning, resource allocation, goal definition, time analysis, activity monitoring, organization, scheduling and priorities definition.

Manufacturing processes typically involve a certain number of preliminary activities including design and processing whose duration can be hardly estimated. Design phase duration can be very variable but in most of the cases does not concern manufacturing enterprise (as in the case studied), for this reason it is not considered in the continuation of the paper. Processing time, especially for highly automated operations, is quite easy to establish. However, increasing the innovativeness of a product, also the difficulties to have an accurate estimation of activities composing process duration become greater especially for highly customized products.

Difficulties in activities duration forecasting are linked to some parameters whose boundaries are often unknown also by product designer. In many cases, limited knowledge about processes, possible risks and the fear of underestimate the duration lead to imprecise too long estimates (Pospieszny et al., 2018). Then, the project management knowledge about suitable techniques and method become more important for enterprises competitiveness (Aliverdi et al., 2013). Nevertheless, the continuous innovation of processes and the availability of increasingly large amounts of data are fundamental aspects that will allow, in the near future, to abandon the traditional techniques and approach the use of machine learning methods. The purpose of this paper is to define a hybrid methodology to estimate the processing time of manufacturing processes and test it on an important Italian company, which operates in the metalworking industry and deals with the production of pressure equipment with a high innovative component. Such a methodology starts from process breakdown into single activities, for each activity the most probable duration has been estimated through physical model or statistic estimation (depending on data availability). Expected duration estimation has been carried out using three-points method introduced in PERT approach. Durations of whole processes have been estimated applying CPM with expected durations, probability distribution (or uncertainly interval around obtained value) found out through simplified PERT method application.

The following of the paper is so organized: section 2 gives a literature review on TM systems, methods and applications in scientific and industrial field. Section 3 presents the methodology proposed by the authors to support the decision on activities duration estimation and consequently on project duration. Section 4 describes the obtained result on faced case study. Section 5 is reserved to conclusions and future researches.

2. Literature review

The theory of Project Management is increasingly circumscribed to use of methods and standard defined by international institutes or associations such as Project Management Institute (PMI), Association for Project Management called PRojects IN Controlled Environments 2 (PRINCE 2), International Project Management Association (IPMA) (Kostalova et al., 2015). The methods of PM can be dived into tools for (*i*) *Costs management* (Cost Benefit Analysis, Financial analysis), (*ii*) *Activities management* (Work Breakdown Structure, Product Breakdown Structure), (*iii*) *Human resources management* (Resource Breakdown Structure, Responsibility Assignment Matrix), (*iv*) *Risk Management* (Risk Breakdown Structure, Monte Carlo Method), and at the end (*v*) *Time management* (Gantt chart, Program Evaluation and Review Technique, Critical Path Method). The result of good time management is increasing enterprise's effectiveness and productivity. Time is one of the three constraints and usually any decision or assumption regarding TM causes effects on cost and scope of every project. For a company whose business is managed by project, the activities duration estimation assumes a crucial importance for allocating resource and accept or reject other projects and other orders.

When the activities durations are known, the best method to provide the minimal duration of the project is the Critical Path Method (CPM) (Ravi Shankar and Sireesha, 2009). CPM was presented in (Kelley Jr and Walker, 1959) and during the years many examples of application are reported in scientific literature. This kind of method (with the necessary changes) have been implemented in a wide range of engineering and management applications such as constructing biogas plant (Zareei, 2018), in general construction projects (Yang and Kao, 2012) and many others (other examples of CPM application are collected in Table 1). CPM has been demonstrated very suitable, in manufacturing industry with sets of activities, linked to each other, for which duration estimation was based on deterministic estimates made using analogy, physical and parametric models.

Table 1: CPM application in scientific literature

Application	Reference
Constructing biogas plant	(Zareei, 2018)
General construction projects	(Yang and Kao, 2012)
General project scheduling	(Castro-Lacouture et al., 2009)
Repetitive construction projects	(Hegazy, 2001)
Manufacturing routing	(Gupta, 1991)
Regulation of mine ventilation	(Chen et al., 2015)
Coordination of clinical care	(Hoffman, 1993)
Marble Processing planning	(Karaca and Onargan, 2007)
Contract Claim	(Wickwire and Smith, 1974)
Manufacturing	(Li et al., 2007)
Parallel and distributed programs	(Yang and Miller., 1988)

Where the products innovation leads to continuous modifications of activities, a deterministic approach become not very effective to have good estimates. For these reasons, authors propose to use Program Evaluation and Review Technique (PERT). This is suitable when activities duration is considered highly uncertain (Wauters and Vanhoucke, 2016). Thus, PERT does not compute duration with a probability of completion of 50% but allows to have a probability distribution (Adlakha and Kulkarni, 1989). In scientific literature many examples of PERT application can be found both in industrial area of interest and out of (Kwak and Jones, 1978; Pontrandolfo, 2000). Some examples of PERT applications are collected in Table 2.

Table 2: PERT application in scientific literature

Application	Reference
R&D scheduling	(Kwak and Jones, 1978)
Project duration	(Pontrandolfo, 2000)
Renewable energy plant	(Lee et al., 2017)
Human service program	(Klosterman, 1979)

According to (Covey et al., 1995) TM systems can be collected in 3 generations sorted by the increasing levels of efficiency and control. The first generation is characterized by simple tools like reminder and to-do lists; to second generation belong schedules with adequate complexity. In this part are presented the concepts of efficiency and activity. The third generation is based on planning and control. In this way medium to long term objective can be defined and reached. The aim of proposed methodology is offer a third-generation estimation system. The innovativeness is combining estimations made from physical and parametrical models, characteristic of manufacturing sector, with the probabilistic approach provided by PERT.

3. Proposed methodology for time management in industrial projects characterized by a high degree of innovation

This work aims to propose a methodology to improve estimation of processing times of industrial products characterized by a high degree of innovation. Such an innovation consists in application of well-known activities on never built before assembled products, not in drastic components modifications or introduction of experimental activities.

This kind of non-repetitive production process is usually managed as a project. Therefore, for the estimation of the processing time, it is possible to refer to the schedule management processes defined by Project Management Institute (2017):

1) Plan Schedule Management: Policies, procedures and documentation establishing for planning, developing, executing and controlling the project. This activity is performed once or at predefined points.
2) Define Activities: the production work packages must be breakdown into the different manufacturing activities needed to realize the product.
3) Sequence Activities: the relationships among the activities must be identified and documented (e.g. by the schedule network diagram)
4) Estimate activity durations: the time required to complete each identified activity, with estimated resources, must be estimated.
5) Develop Schedule: all activities durations and schedule constraints are analysed in order to estimate completion time
6) Control Schedule: the status of project activities has to be monitored to update project progress and manage changes to the schedule baseline to achieve the plan.

In this section it is shown how these processes are traditionally implemented by the deterministic approach, and how they could be improved by the statistical approach proposed in this paper.

3.1 The deterministic approach

Manufacturing companies, like the one described in the case study, usually apply the methodology by choosing a deterministic approach.

For some activities, whose duration has been fixed based on gained experience, analogy technique has been used to estimate the duration. For all other considered activities, it's advisable to use parametric estimation technique based on system physical characteristics or statistical models.

Activities duration estimation based on physical model can be developed only for those processes whose duration is strictly dependent on few characteristic parameters. More in detail, a physical model allows to estimate process duration knowing easily measurable physical quantities (length, thickness etc.) and operating parameters (translation speed, processing speed etc.). Valid physical models can be implemented to estimate cutting duration of sheets considering the thickness, the perimeter to be cut and the cutting speed, while the duration of the welding activity depends on the density of the material, the volume to be welded and the deposition rate of the material). In general, the duration of the i-th activity (D_i) has been calculated through a physical model of the system that takes into account all the quantities considered relevant and also a certain level of productive efficiency.

Activities duration estimation based on statistical model is valid for those activities where a physical model is not available, or it is not possible to have enough information to apply it. In this case it can be possible to identify a statistical model that allows to link the duration of the activity to one or more variables. Here, the correlation was considered significant only for Pearson correlation coefficient values $|r| \geq 0.7$.

Duration of the j-th processes, calculated in most cases through a monovariable linear model that is identified through a regression analysis of historical data, can be inferred with an equation like (1):

$$D_j = a_j + b_j Y_j \qquad (1)$$

where D_j is the duration, a_j and b_j are the coefficients of the regression line and Y_j is the parameter with respect to which the presence of a strong correlation has been evaluated.

After computing the duration, CPM method is applied to estimate entire process duration in a deterministic way. Results allows enterprise to undertake some considerations about total durations and possible interventions to modify them.

3.2 The proposed method: a probabilistic approach based on parametric estimation

Deterministic model is suitable for processes where activities are recurring and working conditions are stable. In productions characterized by high variability and innovations such as those considered, common approach is not ineffective because of its incapacity to manage uncertainty around completion times. In order to overcome this limit, in this work proposes to use the PERT method combining it with the physical and statistical models usually developed by the method described above. To take durations uncertainty into account, three-points estimation method has been applied to calculated duration values of each single activity.

Proposed model is based on simplified PERT approach (Malcolm et al., 1959), using three-points method, considers estimated data coming from previously described techniques as most probable duration and defines standard deviation using available data (Gallagher, 1987; Littlefield and Randolph, 1987).

In particular, applying such a PERT method, durations are considered as random variables represented by a probability density function of Beta type (continuous and defined by two parameters α and β on the unit interval [0,1]), whose variance σ_k^2 is represented by (2):

$$\Sigma\sigma_k^2 = (d_k - c_k)^2/36 \qquad (2)$$

where d_k represents the pessimistic estimate of the generic k-th activity, while c_k is the optimistic one.

Still in the hypothesis of validity of the Beta distribution, the expected duration for the k-th activity, equal to μ_k, can be calculated using (3):

$$\mu_k = (c_k+4m_k+d_k)/6 \qquad (3)$$

in which m_k represents the most probable values (D_i or D_j) for the duration of the activity (Gallagher, 1987; Littlefield and Randolph, 1987), calculated using the spreadsheets developed as described above. In order to determine most probable (m_k) durations, developed model proposes to use parametric (physical or statistical) estimations. For pessimistic (d_k) and optimistic (c_k) durations estimation, statistical approach has been used. Detailed procedure and results are collected in case study section.

After determining expected durations and standard deviations for each activity, CPM method can be applied using expected values. To use simplified PERT method, the entire process duration is considered as a gaussian variable whose expected duration is given by the sum of duration of critical activities and standard deviation equal to the square root of the sum of the square of the standard deviation of the critical path. Furthermore, two hypotheses have to be taken into account: activities are numerous and can be considered stochastically independent. In this way, for each process a duration interval has been calculated.

4. Method's implementation outcomes

4.1 Case study

The enterprise used as case study for this work is a manufacturing company operating in the construction of mechanical products. More in detail, it is one of the most important European company for design and production of high pressure critical items, manufacturing of components for nuclear islands and production of tanks made of special alloys. The enterprise typically operates on orders.

The great variability of workings and the innovation of products, concretized in construction of special and unique parts, makes necessary the use of a method of activity durations estimation.

Project draft is an activity carried out by Proposal Office. The activity begins by acquiring the history of the total duration of the actual workforce for similar orders (for example considering devices with the same material, thickness, diameter, etc.) and based on these data, doing some interpolations, the office obtains the estimated duration for the project to be carried out. Subsequently the working hours are distributed among the various cost centres using spreadsheets with previously written formulas, which consist of a percentage subdivision (the values of which have been obtained on the basis of a past job history) of the total on the individual activities. Such a procedure is strongly based on the experience gained in other projects. After the equipment manufacturing phase has begun a project meeting is called every week to assess the progress of the work. This meeting involves all the project team members and the production manager and is useful to underline any delays and intervene to reduce them redistributing the available resources to give priority to the most important activities.

4.2 Proposed method implementation outcomes

In order to evaluate the effectiveness of the developed method, a comparison with reference method and with actual duration has been made based on three different productions data. All analysed production processes are characterized by three phases: order reception and design, production, shipping.

For initial phases (from order acquisition to the arrival of the ordered materials) and for the final ones (PWHT, hydrotest and shipment preparation), estimates made using standard duration values consolidated over time are used. For this reason, for their duration, a fixed value based on analogous estimations has been imposed. This assumption allows to not consider duration of these activities in the comparisons between two methods. For 11 activities belonging to central phase, durations have been estimated through developed method. Some of them have been estimated using physical models, other through estimations. In particular, for sheet metal cutting, caulking, welding, plating, non-destructive testing, sandblasting and painting sufficient parameters have been available to have a good estimation of activities duration through physical models.

For calendering, assembling and welding, moulding, nozzles preparation and saddles preparation and welding, it has been necessary to resort to regression analysis. In Table 3 all activities, sorted according to the processing sequence, are collected and for each of them the type of estimation and used parameters are specified.

Table 3: Duration estimation method for each activity

Activity	Duration estimation	Used parameter
Nozzles preparation	Regression	Material quantity
Sheet metal cutting	Physical model	Processing length
Caulking	Physical model	Material thickness and processing length
Moulding	Regression	Plate diameter
Welding	Physical model	Material thickness and processing length
Plating	Physical model	Deposited material
Calendering	Regression	Material thickness
Saddles preparation and welding	Regression	Material quantity
Non-destructive testing	Physical model	Percentage of processing time
Assemblingy and welding	Regression	Material quantity
Sandblasting and painting	Physical model	Dimensions and deposited material

The previous estimation method (taken as reference method) did not provide for the duration fluctuation but it outputs only a single value for each duration. That method was based on only parametric estimations made through physical or statistical model. For these reasons, for each activity, a first result has been extrapolated analysing deviations between estimated durations, both not using and using three-point estimation method and real ones.

In addition to expected duration, developed method need some further information to obtain pessimistic and optimistic values. For activities where no information about c_k and d_k were available, the following logic procedure was applied to calculate the respective values:

1. The results of some completed enterprise orders were taken as a reference (when available), with details on the actual duration of the individual activities.
2. For the all the orders, the most probable duration was calculated, through parametric models, for each single k-th activity, using developed spreadsheets. For each k-th activity, whose data were available from completed orders, the minimum duration has been considered as the optimistic estimation (c_k) instead the maximum duration has been considered as the pessimistic one (d_k). For some activities, whose data were not available from completed orders, minimum and maximum durations are estimated consulting the operators.
3. After estimating all the activities durations, σ_k parameters have been calculated in order to estimate σ parameter for each critical activity.

Results of the mean deviation between actual durations (taken as reference) and estimated values of all considered activities, both using simplified PERT technique (only reporting expected values) and not using it, are collected in Table 4. Some activities, regarding the same part, are collected in one general activity. Numbers between square brackets (as [1], [2], etc) are used to distinguish the mechanical machining done on different components.

Table 4: Mean deviations between estimated durations (both not using and using PERT) and actual ones

Activity	$\bar{\Delta}$[%]	$\bar{\Delta}_{PERT}$ [%]
Nozzles preparation + NDT	-2.2	-18.5
Bottom preparation + NDT	6.9	8.1
Saddles preparation + NDT	25	25
Cut + Caulking [1]	3.6	3.6
Calendering	0	-13.3
Welding + NDT [1]	45.7	45.7
Plating + NDT [1]	15.8	15.8
Assembling + Welding + NDT	-1.2	-35.3
Welding + NDT [2]	22.1	22.1
Welding + NDT [3]	7.5	7.5
Welding + NDT [4]	-4,4	-4.4
Welding + NDT [5]	23.3	23.3
Sandblasting + painting	35.2	35.2

Results in Table 4 show that mean expected durations estimated with PERT method have in general a shorter duration than previously used method. However, estimating durations with a single value (as used in the first method) could be complicated and can lead to wrong estimations. PERT method, using probabilistic durations instead of deterministic ones, does not provide a single value but a probabilistic distribution where the expected value is specified. Calculated uncertainty can be positively used to estimate activities durations considering also a time reserve to add to the process. Thus, it is possible to forecast processes duration both using expected values and pessimistic ones in such a way as to provide to manager more information to control activities duration.

Time durations of individual activities, coming from developed method consisting in parametric estimation and three-point method application, have been used to develop CPM analysis on all three selected processes. Application of this method using accomplished results allows to estimate total duration of each process providing a probabilistic distribution for duration.

For considered case studies, duration variability of the three whole processes, is included in respective confidence intervals (Table 5).

Table 5: Comparison of estimated and real durations

Prod.	CPM [d]	3pts [d]	3pts-3σ [d]	3pts+3σ[d]	Real [d]
1	231	252	190.7	313.3	284
2	490	491	427.4	556.6	510
3	182	204	143.4	264.6	183

Having the possibility to consider an interval and not a single value, to estimate whole processes durations enterprise can decide whether to use the expected value or a value shifted towards the optimistic or pessimistic value based on the perception of the risk. Furthermore, the enterprise can operate on entire process duration considering a total duration that is equal to the expected duration plus a time buffer (eventually up to pessimistic estimate). In this case the result is an overall estimate which could still protect the enterprise at least as regards the time aspect (it is clear that for the cost aspect it would be more important to understand on which activities will verify the deviation). Thus, the most important result is the possibility to have better results applying the three-point method linked to CPM method. For some of considered activities the number of available duration sample was not sufficient to have the necessary significance, for this reason results are not statistically reliable however considering the practical point of view obtained results are better than reference method. Indeed, this kind of application led to better duration estimations and, if considering the 3-sigma intervals are considered, all the production durations are well estimated. In Table 5 it is possible to compare results of the developed model (indicated as 3pts) with the previous results (CPM) and the real duration.

5. Conclusions and Future Works

International companies are facing increasingly important challenges to remain on the market. Many of these come from the field of innovation: technological innovation, communications innovation, production innovations and many others. For this reason, some manufacturing companies have to face projects characterized by a high degree of innovation, of which often they cannot define costs and time of realization. Project Management tools and methods are surely useful and effective at this scope, even if their implementation may not be simple because of some difficulties following common standards. In this work the authors proposed a methodology to help these companies to manage time into projects composed of activities never realized before in the same way.

Proposed methodology implements, in original way, traditional methods like correlation analysis, three-points method and CPM. Through this engineering approach, enterprises can estimate in an accurate way expected duration of their processes but also know optimistic and pessimistic durations. In this way, for each process, it is possible to take into account a triad of durations instead of a single value. Intervals between optimistic, expected and pessimistic estimation can be considered to reduce risks related to the uncertainty about innovative projects due to waste of time and unpredictable events. Furthermore, this approach helps to limit the disadvantageous arising from precautionary behaviours (overestimation of durations).

Thanks to the implementation of proposed methodology, for most considered activities it was possible to estimate duration with a greater degree of detail respect to reference method. In this way the method provides a certain flexibility to the processes duration estimation. This aspect is important in activities scheduling and resources allocating.

The global effect of the proposed method is a shorter use of time both during planning and execution phase earning the company advantage of being able to accept a greater number of orders in a same time horizon.

Future research will be addressed to extend the methodology to consider not only the time execution of the activities but also the resources used for these activities. In future works, the authors aim to remove the hypothesis about a single operator for each activity trying to get even better results with the estimate of necessary resources to realize innovative activities.

Another important and very promising development of the work is the possibility to exclude partially or totally traditional TM techniques and use data coming from enterprise to develop innovative procedures using machine learning methods.

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