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Cost and schedule monitoring of industrial building projects: a case study

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Abstract

Performance measurement is a helpful tool for taking corrective actions and controlling a project as far as this enables accurate time and cost forecasts during the first stages of the construction effort when the management team still has opportunities to make adjustments. This paper overcomes the dilemma of practicability and predictability of traditional estimates at completion based on early progress measurement by presenting the empirical results from the construction project of an industrial facility. The case may be a reference practice for assessing time and cost performance measurement of any building, whose layout can be reasonably partitioned into repeatable portions. In such circumstances, an effectively managed traditional earned value method and appropriate metrics for computing performance provide project managers with accurate forecasts as useful tools for successful project management and control.

Introduction

An effective monitoring system is a basic requirement for tracking cost, time and quality in a construction project. Based on project performance measurement, the project team can activate a project control process to ameliorate any issues and return the project the more in line as possible to its scheduled course (Ritz 1994). Project monitoring and control is a recurring process involving comparison of actual to scheduled performance, estimates to completion and corrective actions based on such forecasts. To keep project overruns on track requires either performance adjustments or revision of contract targets with regard to schedule, price and level of quality.

Important components of an effective monitoring system are the establishment at the planning phase of an appropriate scope breakdown, a useful performance metrics, a management scheme organized for identifying and reporting of performance, as well as accurate performance forecasting.

Activating any adjustment late into the project is often ineffective and expensive (Sterman 1992; Nepal et al. 2006): the later the corrective action, the less the ability of influencing the project outcomes. Thus, the most effective managerial control is the one carried out during planning, design and the early stages of the construction effort. Yet, any initial project control must face the inherent uncertainty of the construction startup process and the availability of a reliable set of progress information, which will become on hand as activities unfold.

To this end, project managers have to make use of early cost and time estimates at completion based on anticipated progress reporting and Earned Value (EV) analysis as a crucial tool for undertaking any control strategy. The failure in predicting schedule and cost to completion since the first steps of the project may result in time and cost overruns and jeopardize the construction contract targets.

Project Monitoring Issues

The methods for project cost and schedule performance monitoring have been largely explored. Yet, beside attempts to get to standard practices (Project Management Institute 2005), projects from different sectors require specific approaches. Construction projects, in particular, involve tailored methods for decomposing the complex scope of work into work items and tasks with regard to cost and schedule tracking (Woodward 1997; Hendrickson 1998; Winch 2002; etc.). A proper Work Breakdown Structure (WBS) to serve as a basis for progress measurement allows for EV accounting at the detailed level, as well as cost and schedule integrated monitoring and forecasting at the project level (Eldin 1989; Jung and Woo 2004).

Before entering the specific practical situation of a modular industrial building project, this section illustrates the main issues to consider in construction progress monitoring and EV analysis.

Cost and Schedule Breakdowns Integration

For the theoretical purpose of project monitoring, items in the WBS are designated as job cost accounts for recording and comparison of expenses incurred during development to the original estimates. Yet, the process is far more complex from a practical point of view since work and cost breakdown accounts usually do not match. Typically, the WBS is prepared to manage the construction sequencing and duration of activities, while cost accounts cascade from grouping construction elements in systems and subsystems.

Yang et al. (2007) make a review of the various models available to measure progress based on the WBS and the related cost accounts. The challenge is to make accurate measuring of progress at the lowest level of the scope breakdown without incurring cumbersome data-handling workloads that may result in impracticability of the method. Also, cost and schedule progress measurements can integrate if either the work items perfectly match cost accounts or a viable matching between WBS and job cost elements is determined at a given breakdown level, usually the task's detailed one. The problem accrues in a separate design and build delivery system as far as the cost breakdown derives from the engineer's estimates that are traditionally prepared during the detailed design phase: in such a situation the contract estimates do not align with the work breakdown designed by the contractor or the agency project manager to implement and manage the physical construction improvement.

Progress Measurement

To produce a reliable evaluation of the actual status of the project, an effective impartial construction surveying as well as a rigorous system for timely collection and reporting of information are necessary to provide both the owner and the contractor with accurate and objective assessment of performance.

The objectivity of progress estimation is a crucial issue to consider in the task of monitoring the project status. Several are the metrics to evaluate the physical progress of individual activities (U.S. DoE 1980, Fleming 1992) depending on the type of task.

In the case of tasks that involve production of easily measured deliverables, the “discrete effort” or “units completed” are practicable and viable metrics for assessing the actual situation.

The “on/off” technique is a useful approach when accounts cannot be physically measured: progress of an item is 100 percent complete when the job is formally accepted as finished. Since the progress record of underway tasks is zero, the method may not result in an underestimation of performance only if measurement is carried out at the very detailed level of elementary tasks. To overcome the problem, different conventional metrics may be established as a set of “incremental milestones”, such as the ones required to prepare, submit and approve a drawing. In this case, conventional percentages are associated to each step of the process based on the number of work-hours, or other quantities, estimated to be required to that point in relation to the total (e.g.: 60% at first issue of drawing, 70% returned with comments, 80% other issues, 95% approved, 100% ready for construction). The incremental milestone approach well applies to longer activities and to the measurement of WBS items at a higher level than the detailed task one.

Progress of indirect cost may be assessed in terms of apportioned effort in relation to the progress of activities they are linked to.

Of course, it is possible to use other methods to measure actual progress of individual work packages and tasks. In any case, a flexible use of all methods permits that each item is recorded in the more suitable way.

Once the advancement of individual tasks has been assessed, the aggregated progress at any level of the WBS up to the project level is calculated as a weighted summation of individual lower level progress percentages, where weights are calculated based on the original project budget.

Estimates at Completion

Based on the Budgeted Cost of Work Scheduled (BCWS) and measurement of the Actual Cost of Work Performed (ACWP) at the project level, it is possible to report the discrepancy between the current performance versus the scheduled one by the calculation of EV, referred to as the Budgeted Cost of Work Performed (BCWP).

The Cost Variance (CV), and the Schedule Variance (SV), as well as the Cost Performance Index (CPI) and the Schedule Performance Index (SPI) are factors of past behavior to use as trends for predicting future targets, if no corrective actions are undertaken (CII 2004).

Thus, the cost estimate at completion (EAC) and the time estimate at completion (TEAC) can be calculated by extrapolating the actual performance to the end of the project (Project Management Institute 2005). The following formulae indicate that estimates to completion are consistent with the original budget at completion (BAC) and planned duration (D), adjusted by the corresponding performance factor:

$$EAC = ACWP + (BAC\text{-}BCWP) / CPI = BAC / CPI \quad (1)$$

$$TEAC = (BAC / SPI) / (BAC / D) = D / SPI \quad (2)$$

The following formula (Henderson 2005) is closely equivalent to Equation 2:

$$TEAC = T + (D - T) \text{ x } \frac{(BAC - BCWP)}{(BAC - BCWS) \text{ x } SPI}, \text{ where T is the time now} \quad (3)$$

Problems may arise from the index-based formulae above with regard to the accuracy of estimating both cost and time.

Some corrections in Equation 1 may help in better predicting the cost at completion. Christensen (1999), with reference to U.S. defense contracts, remarks that a different performance factor in Equation 1 may be used to account for the integrated influence of the schedule variance to the cost performance: a bad SPI may be an indicator of future cost overruns. Thus, the performance index for estimating the cost at completion may be either CPI, or SPI, or a combination of both indices (e.g.: CPI x SPI; 0.8 CPI + 0.2 SPI). The diverse adjustments lead to a range of EACs, where the CPI factor calculation is a reasonable floor to the final cost, and the one obtained by using the product of CPI and SPI is a sufficiently large indication of the maximum final cost (Christensen 1996).

Also, during the very first stages of a project the CPI fluctuates so that it is not to be considered as a reliable source of future indication, while it has been researched (Lipke 2005) that CPI tends to stabilize by the time the project is 20 percent complete. Furthermore, CPI is likely to worsen from that point in time as the project progresses. This is mainly due to delay, rescheduling and rework, which increase as more activities unfold (DoE 1980; Oberlander 1993). Accordingly, Lipke (2005) has experimentally determined that in engineering projects a correction factor to the CPI allows for calculating the EAC upper bound. The maximum correction factor equals 0.1 and Equation 1 may be rewritten as:

$$BAC / CPI < EAC < BAC / (CPI – 0.1) \quad (4)$$

With sensible variation, select index-based formulas allow in any case for an accurate evaluation of EAC and alternative nonlinear regression-based models are not as practicable compared to the little additional precision they provide (Christensen et al. 1995).

In contrast, index-based estimation of time at completion is trickier and may require more complex metrics. Equations 2 and 3 are functions of the SPI, which has a defect inherent with the calculation metrics (CPI = BCWP / BCWS): as far as the project progresses the SPI tends to get close to 1 even if the project is behind schedule. Indeed, at the finish date when the work performed (WP) equals the work scheduled (WS), the schedule variance is nil and the schedule index is 1. As a result, the SPI and the associated formulae are useful only during the initial stages of the project development (Fleming 1991).

Index-based calculations like the ones of Equations 2 and 3 have some restrictions. In fact, the linear model assumes that the latest measured performance will remain the same until the project is complete without taking into account any late performance change that typically apply to construction projects. Also, the elements used for progress measurement must be broken down with a good level of granularity and have rather homogeneous budgets and durations, as to define a cumulated S-curve of actual cost that may be reasonably approximated to a straight line.

To overcome these limitations and to enable earned value metrics not only for cost, but also for time estimates, it is proposed that TEAC are calculated by the help of non-linear methods. It is suggested to use the logistics equation for modeling the shape of project cost accrued over time. The logistics model better interpolates the nonlinear S-curve and allows for evaluating TEAC by considering the specific initial behavior of a project schedule. The S-curve may be defined by several mathematical formulae, such as the Verhulst model or the Gompertz curve (Weisstein 1999). For the purpose of this paper, this is defined as:

$$\text{Progress} = K / (1 + C\, e^{-h\,\text{Time}}) \tag{5}$$

where the parameters K, C and h are experimentally set as to define a curve that approximates the cumulated actual progress curve line as periodically recorded by the project monitoring team during the initial stages of the project (time series of data from at least three progress measurement reports).

This paper is aimed at demonstrating how these issues may be solved in construction project management with a special focus on an industrial facility renovation project. In particular, the above methods for calculating estimates at completion well apply to the case and this prove that accurate index-based EAC and nonlinear TEAC can be predicted as early as when the project is 20 percent complete.

Case-Study

Following is a sample implementation of a project control method for managing construction projects of modular facilities, such as industrial ones that typically have repetitive structural frames. In particular, the case-project is about the renewal of a portion of a large industrial facility in Torino (Italy) to serve as headquarters to the Abarth Racing Team and as various corporate services to Case New Holland. Abarth&C. S.p.A. is a Fiat Group Automobiles company that produces race car kitting and tuning. Case New Holland is a Fiat Group manufacturer of construction equipment and agricultural vehicles.

The construction works, planned to last 189 calendar-days from June 30th, 2007 to January 5th, 2008, involve a 50.000 square-meter portion of a former manufacturing plant layout with two aside service lane buildings (Fig. 1).

Fig. 1. Layout of the case-study building

All sectors of the facility have modular steel structures: the mechanical shop named Plant #83 is composed of approximately 200 main units of twelve-meter foursquare frames, Building #1 has a pair of repetitive sections, and Building #2 is made of five steel frame sub-areas.

The project is delivered with a traditional design-bid-build contracting system. The owner Fiat Partecipazioni S.p.A. (Holdings) engages the a-fee professional services of an engineering company to produce the basic and detailed design, as well as site supervision and project control. The engineering firm acts as an agency construction manager overseeing the design.

The 21.4 million euro construction contract is awarded based on a time and lump-sum price proposal competition to a general contractor paid based on monthly job progress. The contract price is agreed with reference to the engineer's detailed estimate bill of quantities. The construction scope includes all structural and architectural works, piped, power, electrical and HVAC systems.

Planning, Budgeting and Scheduling

With the purpose of easily budgeting, scheduling and monitoring the project, the scope is broken down into four hierarchical levels of work elements (Fig. 2). The first level of the WBS is a spatial partition of the facility layout into 19 distinct areas, where the two aside buildings are broken down by floor and the machine shop #83 is separated into spaces that have a different function for the final users. The construction work required for each area is decomposed into three categories of elements, namely: architectural works, from structures to finishes; electrical services; and fluid services, including piped, ducted, thermal and mechanical systems. Categories are then subdivided into work packages, which are finally decomposed into detailed activities.

Fig. 2. Project WBS

The engineer's estimates provide specifications and quantities for all identified contract work elements that are needed for the renewal of the entire facility. Elementary activities in the WBS are portions of the total work element quantity with regard to one of the 19 specific layout areas. Thus, a complete univocal code (Table 1) is defined to match WBS activities with the contract work element identifications to produce the budget as a Cost Breakdown Structure (CBS).

Table 1. CBS coding system of a sample activity

The total project WBS has more than 1,200 construction activities to be executed in seven months. To have a manageable number of elements and a handy framework for monitoring and communication, the agency project schedule is based on the work package level of the WBS. The project team has the primary objective of delivering usable portions of the project as soon as they are finished in order to assure prompt occupancy and industrial operations. The WBS proves to be effective for considering different layout areas as separate schedule milestones.

Below is the baseline S-curve of the BCWS out of original cost budgeting and time scheduling. The schedule is based on work package sequencing and estimated durations, and it takes into account all constraints and milestones agreed upon the contract (Fig. 3).

Fig. 3. S-curve of the project Budgeted Cost of Work Scheduled

Field Progress Measurement

The main problem that a project control system faces is the great amount of details and the choice of the proper WBS level for measuring the job progress (Riggs 2004).

Due to both the impracticability of monitoring the number of individual elementary tasks based on actual quantity surveying and the hardness in assessing a reliable progress measurement of the work performed (WP) based on work packages, an intermediate grouping of activities is introduced as a control element, similarly to a work item level.

Work items are specifically defined with regard to the nature and scope of each work package and assigned a percentage weight of the work package's original budget. Also, a common work item, defined as "Z - Finishes", is used for all work package breakdowns to refer to the many, and usually neglected, minor activities required for substantial final completion of any work package. The Z work item was agreed between the construction manager and the contractor to be worth 5% of the work package's budget.

For example, the work package code 002.001.001 "Demolitions" includes 21 activities just for the first floor of Building #2. Demolition tasks are grouped into four work items, namely: a) demolitions in general, b) doors demolition, c) windows demolitions and z) finishing, which in this occurrence is the job to be performed for disposal of demolished materials and meticulous cleaning. Below is another example of work item definition for monitoring the replacement of the existing asbestos cement rooftop (Fig. 4). Table 2 also shows the calculation of the relative budget weights of work items that are assumed to be totally worth 95%, since the remaining 5% is assumed to be released at completion.

Fig. 4. Progress measurement elements grouping the roofing construction detailed activities

Table 2. Sample calculation of work item weights based on budget

The decomposition of a work package into measurable items, which are different from the price items agreed upon the contract, may not be a simple task and may result in disputes over underestimation or overestimation of monthly job progress, which in turn affects payments. For example, it is opportune that the activities involving supply of materials are separately considered as completed, as far as the material is shipped to the site and accepted by the owner before installation.

It is worth remarking that the work item breakdown is not applied to some work packages that count a few construction tasks. In such situations the work package is the progress control element.

Whatever the control element, the "on/off" technique is chosen for measuring the job done. The progress of an individual control element is 100 percent complete only at the point in time it is substantially completed.

To this end, it is required that the facility areas are decomposed in small homogeneous units of space. The task is easily done thanks to the orthogonal and repetitive structural frame of the industrial plant layout. For instance, Building #2 is a 180 meter [197 yards] long and 16 meter [17.5 yards] large open plan, which is partitioned into 5 similar main modules delimited by arrows of columns and four staircases; these sub-areas are designated to host five office "lofts" numbered from 1 to 5. Also the main Plant #83 is suitable for being split into a number of similar square units of space (Fig. 1).

For each one of the 36 project work packages, a spreadsheet displays the physical layout decomposed into sub-areas. Individual modular units of space contain a cell list of items, whose work progress has to be measured (Fig. 5).

Fig. 5. Sample of the progress reporting worksheet

As far as a work item in a single sub-area is quality-checked as completed by a field superintendent, a one mark is recorded on the report sheet and this becomes an input to the weighted sum calculation of the total percent progress of the work package. In fact, the percent completion of a single sub-area is the weighted total of percent progress of each work item, while the work package progress is obtained by dividing the summation of all space unit percent progresses by the total number of sub-areas (Equation 6).

$$\text{Work package percent completion} = \Sigma\ (\text{unit \% progress}) / \text{unit count} \qquad (6)$$

A cell coloring function of the spreadsheet supports a visual understanding of the construction workflow and better communication of the weekly status reporting. Larger spreadsheets are used for the total Plant #83 facility area, similarly to Fig. 5.

As a summary, the monitoring process of a modular facility requires the following steps: first, the layout must be decomposed into small uniform units of space areas with reference to the structural frame; second, the activities required for one or more sub-areas have to be grouped into "on/off" measurable elements either under the form of work packages or, in case, as work items; finally, the total progress of the project is calculated as the weighted summation of individual bottom elements up to the top level of the WBS.

This WBS approach and the connection of the progress spreadsheets to the project control software enable handy preparation of various summary reports. In particular, on a monthly basis, by executing a specific command implemented on the project software, the percent progress of a work package calculated on the spreadsheet file is used to update the percent complete attribute of the corresponding work package in the WBS. As a result, the contractor is paid the lump-sum price multiplied by the monthly top-level project aggregated percent progress. This amount of money can be also reported by WBS level (e.g.: by job categories or areas) as the summation of each work element budget multiplied by the associated percent progress.

Earned Value and Performance Reporting

As though the site opens in June, the effective construction date is July 1st. During the first months, conditions of the rooftop different from that specified, as well as the need of using helicopters for removing the existing roof slabs in specific nighttime slots, require a change order that affects both cost and duration. Also, other minor design additions are ordered and executed with no extra time and cost, as a compensation of works that are taken out of the original scope. After the September 30th project status assessment, the agency project team, the contractor and the owner make a major project review for understanding the causes of delay and taking corrective actions to face the estimated time overrun at completion. As a result, since the project targets are negotiated to be not revised, the contractor expedites the electrical and fluid systems job with triple shifts, while the owner accepts shorter procedures for material acceptance and process quality check. These decisions were taken based on the information provided by the project control system and reporting.

Table 3 is the EV monthly reporting summary with performance indices, calculated according to previous definitions. As stated above (Lipke 2005), the report and related Fig. 7 show the typical cost and time performance behavior, where the cost performance tends to stabilize when the construction project is 20 percent complete and to worsen as far as the project progresses from that point in time. Adjustments are typically undertaken for improving the cost performance late at the end of the construction effort. The report also demonstrates that the SPI is not a steady and reliable indicator from the point in time the project is 20 percent complete.

Table 3. EV monthly reports

The job progress report at the first level of the WBS (area codes) is also a useful tool for making adjustments to the sequencing of construction operations basically aimed at meeting contract milestones. The chart below (Fig. 6) helps detecting where the delay is more important and in which area of the facility the job is ahead of time.

Fig. 6. Job progress reporting with comparison of WP versus WS by main areas of the facility layout

Cost and Time Estimates at Completion

Based on progress statusing and EV reporting, cost and time estimates at completion are calculated at each monthly review step using linear Equations 1 and 3. The results are displayed in Table 3.

For example, in September, when the work performed progress is far 20.76% and the ACWP is worth 21.32% of the original budget, it is estimated a 2.02% cost overrun to project completion. In fact:

EAC (as a fraction of original budget) = BAC / CPI = 100% / 0.974… = 102.76% of BAC

With Equation 4, the resulting EAC raises to 113.6% of the original budget. These values are considered as the lower and upper bound cost estimates.

Similarly, at the end of September, since the planned project duration is 189 days, linear Equation 3 allows for calculating a 38-day estimated time overrun to completion.

Since the CPI tends to stabilize when the project is 20 percent complete (Fig. 7), EAC are reliable only after that point in time.

Fig. 7. Behavior of the project SPI and CPI

Likewise, TEAC are consistent if calculated when the project is between 20 and 70 percent complete, to avoid any wrong usage of the SPI. In fact, the analysis of the SPI trend along the project development as reported in Fig. 7, demonstrates that index-based calculations that are produced late into the project may result in an underestimation of the expected project duration because the BCWP tends to equal the BCWS as the project activities unfold.

With the purpose of ameliorating the duration estimate at completion, the project controller makes also logistic-curve-based calculations as in Equation 5, where K, C and h are parameters researched as to fit the historical curve of the WP, as cumulated so far. Table 4 provides the logistic-based estimated work progress resulting from setting the logistic curve parameters that better interpolates the past series of WP data with regard to the project development up to September 30th, namely K equal to 1.05; C worth 100; and h equal to 1.06.

Table 4. Project actual completion estimated with alternative index-based and logistic-based method

Fig. 8. Estimation of work progress to completion

In a general logistic equation, the parameter K is defined as "carrying capacity" because it is the upper limit of the variable growth, and this usually equals 1, referred to as 100%. As far as the progress variable is concerned in Equation 5, project managers would expect that K equals 1 because 100% is the total work to be done for finishing the project, unless variations are made to the size of the original total scope of work. In reality, it is necessary that K is greater than 1 for not having a mathematical upper limit, which does not simulate a point in time when the project can be finished. With this value, the modeler would rather simulate a so-called 90% completion syndrome (Sterman 1992). Here, K equals 1.05 to return the "5% Finishes (work item Z)" assumption: in a construction project a residual 5% of scope is typically delivered at substantial completion.

With regard to the other parameters of the equation, C is the total percent original scope to be performed (100), and h is then determined by imposing WP percent progress values to fit the logistic equation. The curve-fitting parameter is obtained by reiteration as to minimize the summation of square differences between the logistic-based estimate and the actual percent progresses: Δ^2, where Δ equals the logistic-based estimate percent progress minus the actual percent progress (see Appendix). The curve is then qualitatively validated by comparison to actual progress S-curves of past similar projects. The resulting curve is a good approximation of the past WP line that can be used to estimate the work progress trend to completion and the related project actual completion (Fig. 8).

With the logistic equation, time overrun is calculated within 29 days, less than the one determined using index-based linear estimates.

The logistic method is suitable for estimating time at completion, but it may be awkward for the cost. In fact, one should use Equation 5 for simulating the ACWP variable behavior, rather than the WP, and should establish the value of K as the maximum limit of actual cost at completion, which is the same unknown variable the modeler wishes to estimate.

Findings and Results

The following chart (Table 5) compares index-based and logistic-curve cost and time EAC with the final actual cost and duration of the project that is recorded on the completion date January 28th, 2008. The estimates are the ones calculated at the September 2007 project review, when the progress is approximately 21% and the project is two and a-half months into the construction period and four months before actual completion.

This example proves that estimates are reliably predicted at the point in time the project actual progress is 20 percent complete.

Table 5. Comparison between estimates and final actual cost and duration

The report also shows that nonlinear time estimates gives a better indication of the total duration of the project at completion because the logistic-equation allows for overcoming the SPI bias.

More important is the practical implication and the usefulness of performance assessment and estimates to the project team for undertaking control actions. The recovering from cost overruns in the last months of construction (see the CPI oscillation in Fig. 7) was directed because of the predictions in the previous months, and this involved both scope and quality changes, such as cutting corners of some components of electrical equipment, and level of finishes in some service spaces of the facility.

Lessons Learned

The case method used for tracking and estimating the project cost and time at completion was successful with regard to several aspects. First, the measurement of the scope progress as completed work items for modular units of space enabled standardized site inspection and ongoing quality assurance of the work performed, for a short and prompt final acceptance of the project. Also, the granularity of the work item proved to give sufficient information while avoiding an expensive progress measurement task of construction detailed activities.

Second, despite 2.40% of final cost overrun and approximately 11% of time overrun, the owner was still satisfied with the project outcomes because of the reliability of the monitoring metrics and process in predicting and communicating any possible deviations from the contract targets far ahead of the contract deadline.

Finally, the reliability of the performance monitoring and forecasting system was an important factor for the project team to force expediting construction, regardless of the contractor's belief that a sufficient time buffer was included into the original schedule to meet the original deadline.

As a result, a survey carried out to assess feedback on the project monitoring method indicated a good level of satisfaction by the owner with specific regard to timeliness and reliability of data. Moreover, the contractor showed even larger satisfaction on the usefulness and fairness of the method: the contractor definitely benefitted from a system that was originally designed for controlling the project from the owner's perspective.

Conclusions

With reference to the case of an industrial building project, this paper proposes a method for effective monitoring of progress as a process of milestone assessment of layout portions of work completed. Based on progress recording, it is demonstrated that linear estimates at completion are a reliable source of information for project cost control from the point in time the project is 20 percent complete and that time at completion is better estimated with the usage of a logistic model.

The proposed method is a way of overcoming the traditional assessment of project linear performance. The linear approach is a useful simplification of the behaviour of organizational systems; this does not take into account the combined action of the several actors of a complex project, the rework and feedbacks that typically delay the project development (Sterman 1992). The S-curve is a better representation of such delayed effects affecting productivity and work rate late into the project. Also, the method is a handy compromise between forecast reliability and data availability and management.

Further research is in the field of regression-based calculation of the logistics equation and in analyzing additional feedbacks that typically affect cost and time overruns.

Notation

ACWP	Actual Cost of Work Performed
BAC	Budget At Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
CBS	Cost Breakdown Structure
CPI = BCWP / ACWP	Cost Performance Index
CV = BCWP – ACWP	Cost Variance
D	planned Duration
EAC	Estimate At Completion
EV = BCWP	Earned Value
SPI = BCWP / BCWS	Schedule Performance Index
SV = BCWP – BCWS	Schedule Variance
T	Time, referred to as the date of actual measurement
TEAC	Time Estimate At Completion
w	Weight, as fraction of the original total budget
WBS	Work Breakdown Structure
WI	Work Item
WP	Work Performed
WS	Work Scheduled

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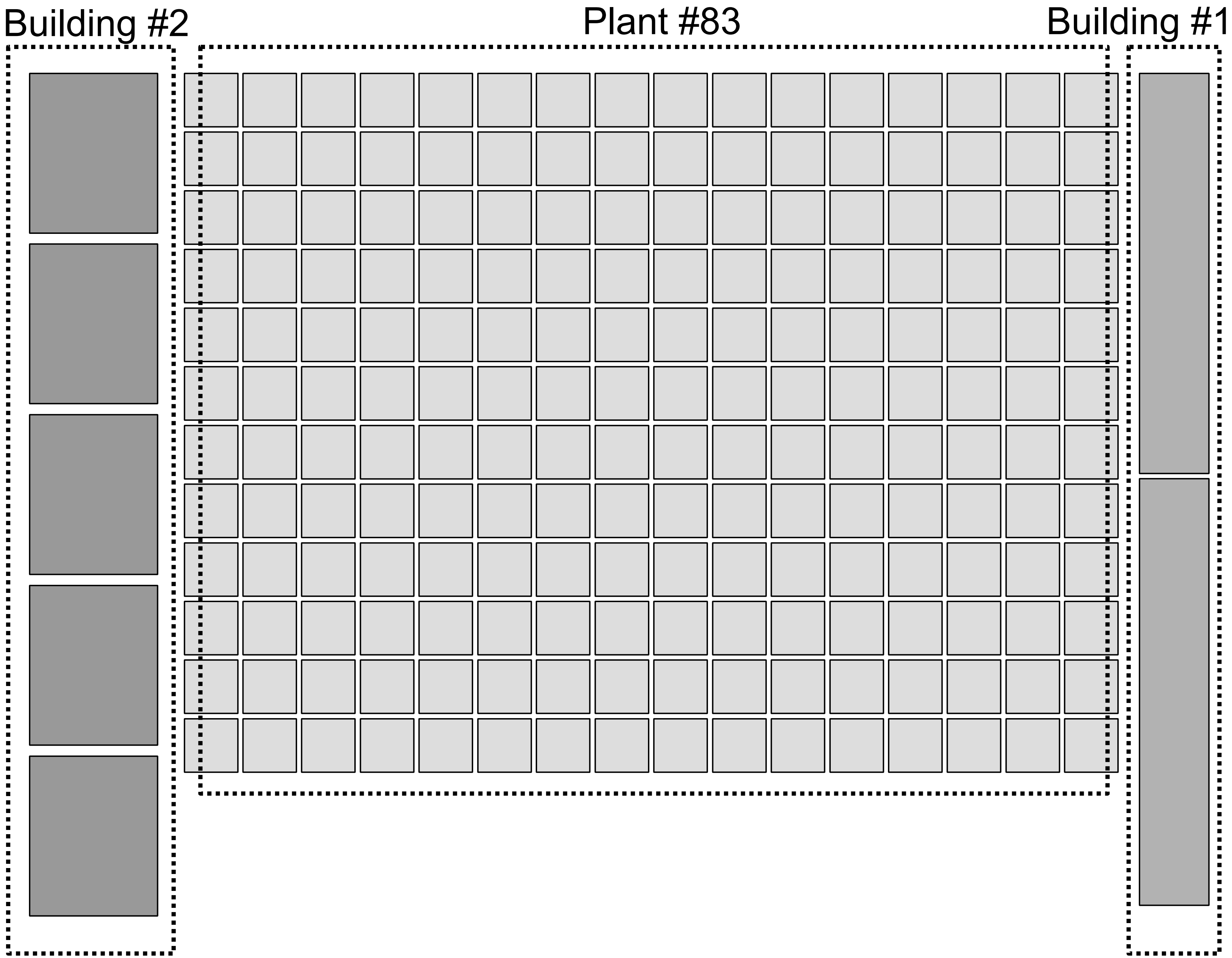
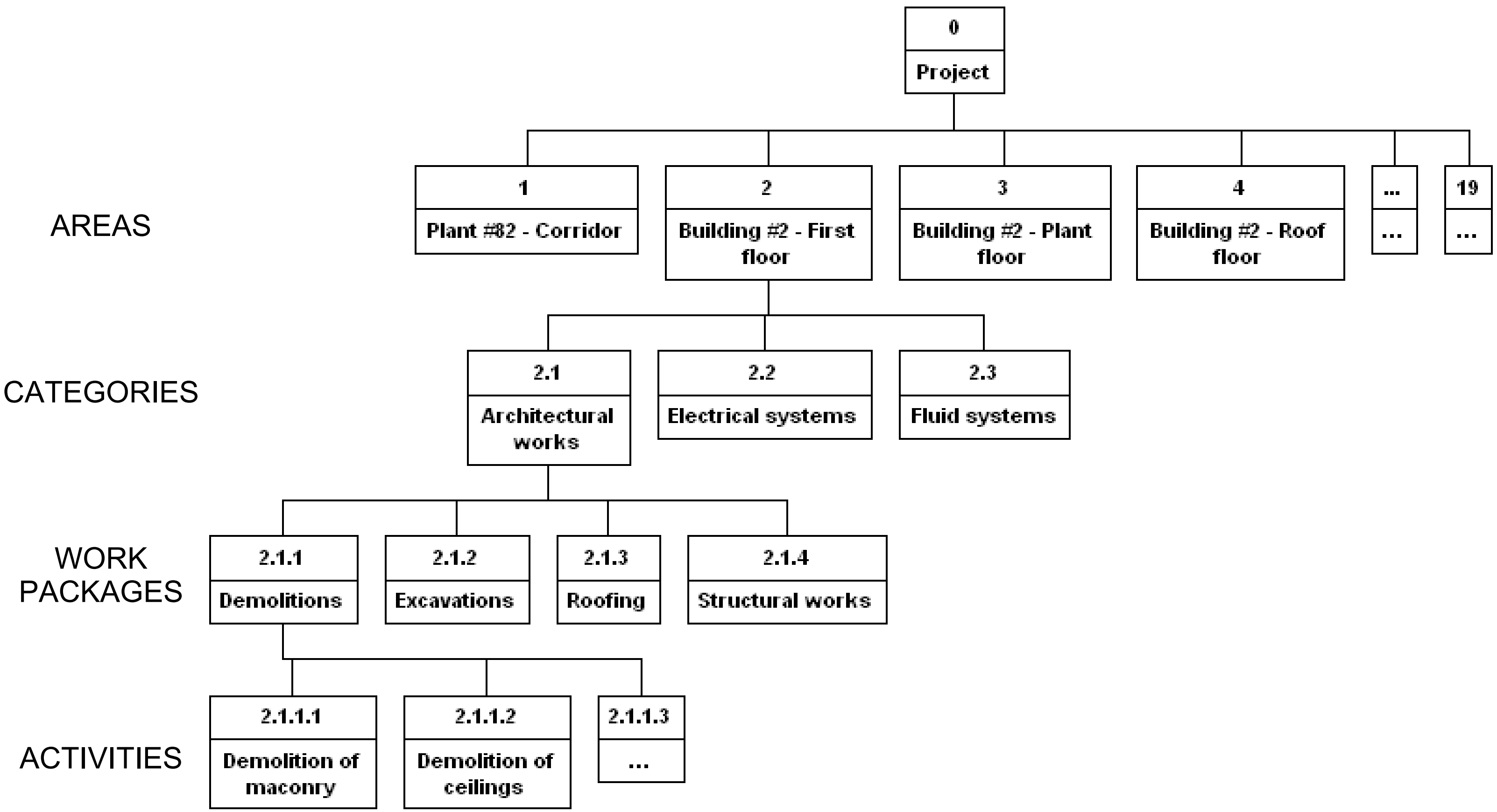
Appendix

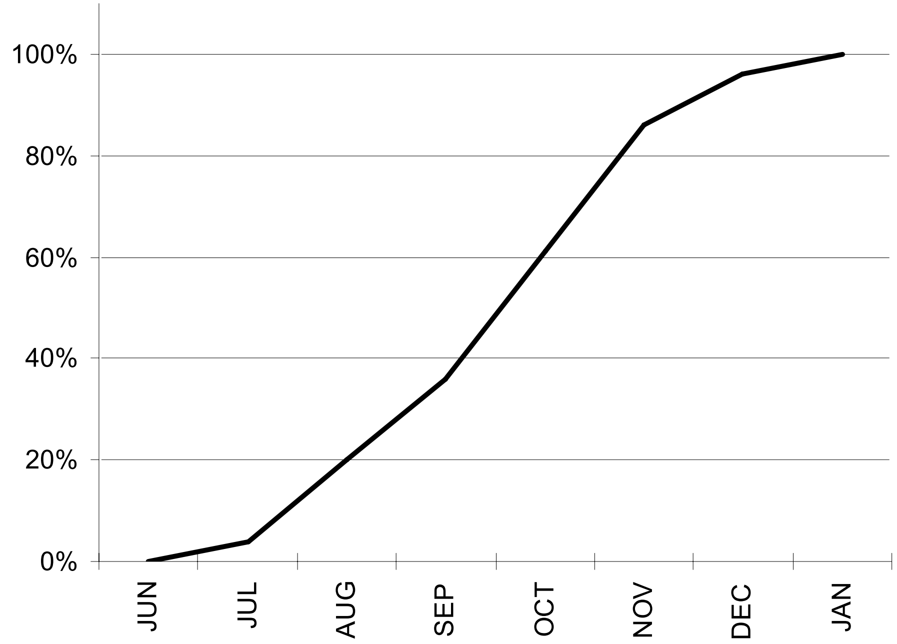
The chart below shows the logistic curve-fitting determination of the h parameter. The bottom line is a monotone curve with a sole minimum point corresponding to the appropriate value of the parameter

	K	1,05		1,05		1,05		1,05		1,05		1,05	
	C	100		100		100		100		100		100	
	h	0,90		1,00		1,04		1,06		1,08		1,10	
WS	WP	logistic-based estimate	Δ (logistic - WP)	estimate	Δ	estimate	Δ	estimate	Δ	estimate	Δ	estimate	Δ
0,00%	0,00%	1,04%	1,04%	1,04%	1,04%	1,04%	1,04%	1,04%	1,04%	1,04%	1,04%	1,04%	1,04%
4,00%	0,58%	2,52%	1,94%	2,78%	2,20%	2,89%	2,31%	2,93%	2,35%	3,00%	2,42%	3,06%	2,48%
20,00%	6,23%	5,99%	-0,24%	7,22%	0,99%	7,78%	1,55%	8,00%	1,77%	8,38%	2,15%	8,69%	2,46%
36,00%	20,76%	13,60%	-7,16%	17,56%	-3,20%	19,39%	-1,37%	20,11%	-0,65%	21,36%	0,60%	22,40%	1,64%
		Σ (Δ2)	**0,0056**		**0,0017**		**0,0011**		**0,0010**		**0,0012**		**0,0016**


Building #2
Plant #83
Building #1


0
Project
AREAS
1
Plant #82 - Corridor
2
Building #2 - First floor
3
Building #2 - Plant floor
4
Building #2 - Roof floor
...
...
19
...
CATEGORIES
2.1
Architectural works
2.2
Electrical systems
2.3
Fluid systems
WORK PACKAGES
2.1.1
Demolitions
2.1.2
Excavations
2.1.3
Roofing
2.1.4
Structural works
ACTIVITIES
2.1.1.1
Demolition of maconry
2.1.1.2
Demolition of ceilings
2.1.1.3
...

Month	BCWS	€
JUN	0.00%	€ 0.00
JUL	4.00%	€ 856,000.00
AUG	20.00%	€ 4,280,000.00
SEP	36.00%	€ 7,704,000.00
OCT	61.00%	€ 13,054,000.00
NOV	86.00%	€ 18,404,000.00
DEC	96.00%	€ 20,544,000.00
JAN	100.00%	€ 21,400,000.00



002.001.003 Roofing

002.001.003.001 Steel plates

002.001.003.002 Decontamination

002.001.003.003 Transportation of asbestos

002.001.003.004 Removal of suspensions

002.001.003.005 Steel structure

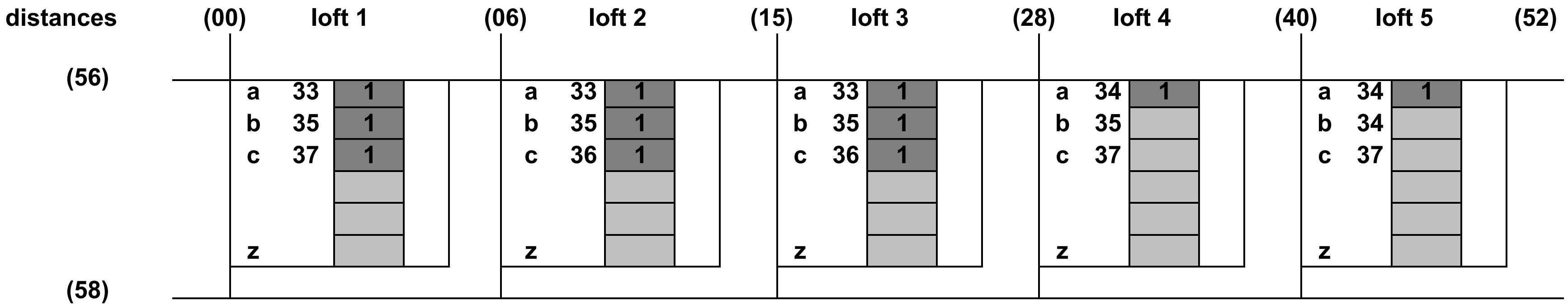
....

002.001.001.046 Piping grilles

46 tasks

ITEM	DESCRIPTION
a	Asbestos plating
b	Removal
c	Disposal
d	Cladding
e	Drain piping
z	Finishing

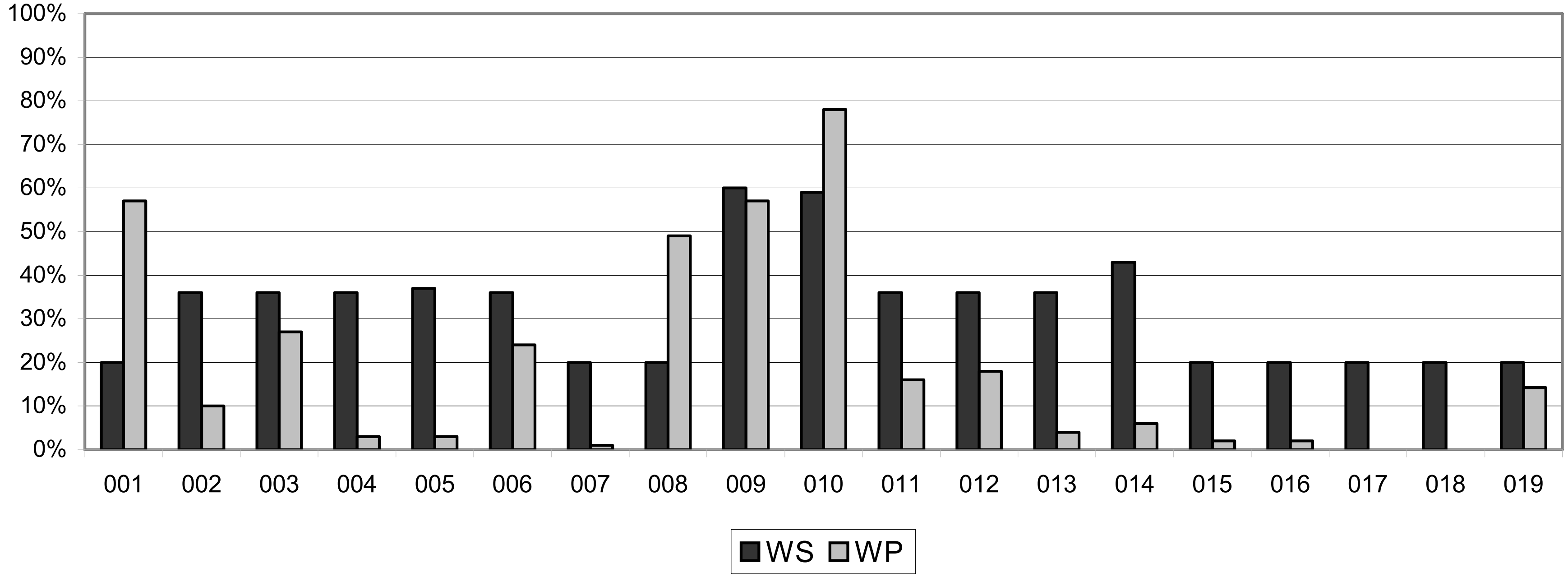
	CODE	September 30, 2008 (Week 39)
area	002	Building#2 First floor
category	001	Architectural works
work package	001	Demolitions

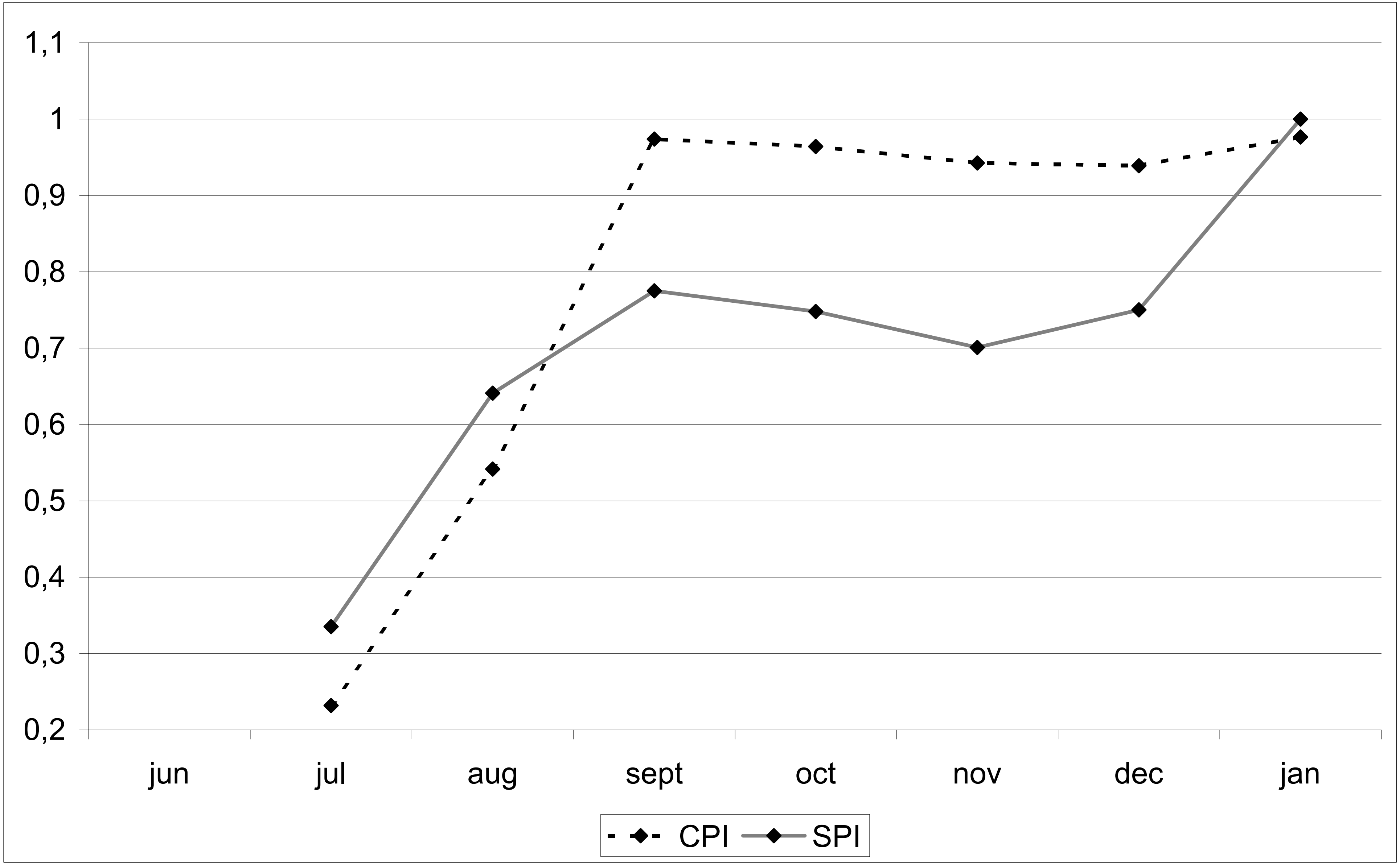


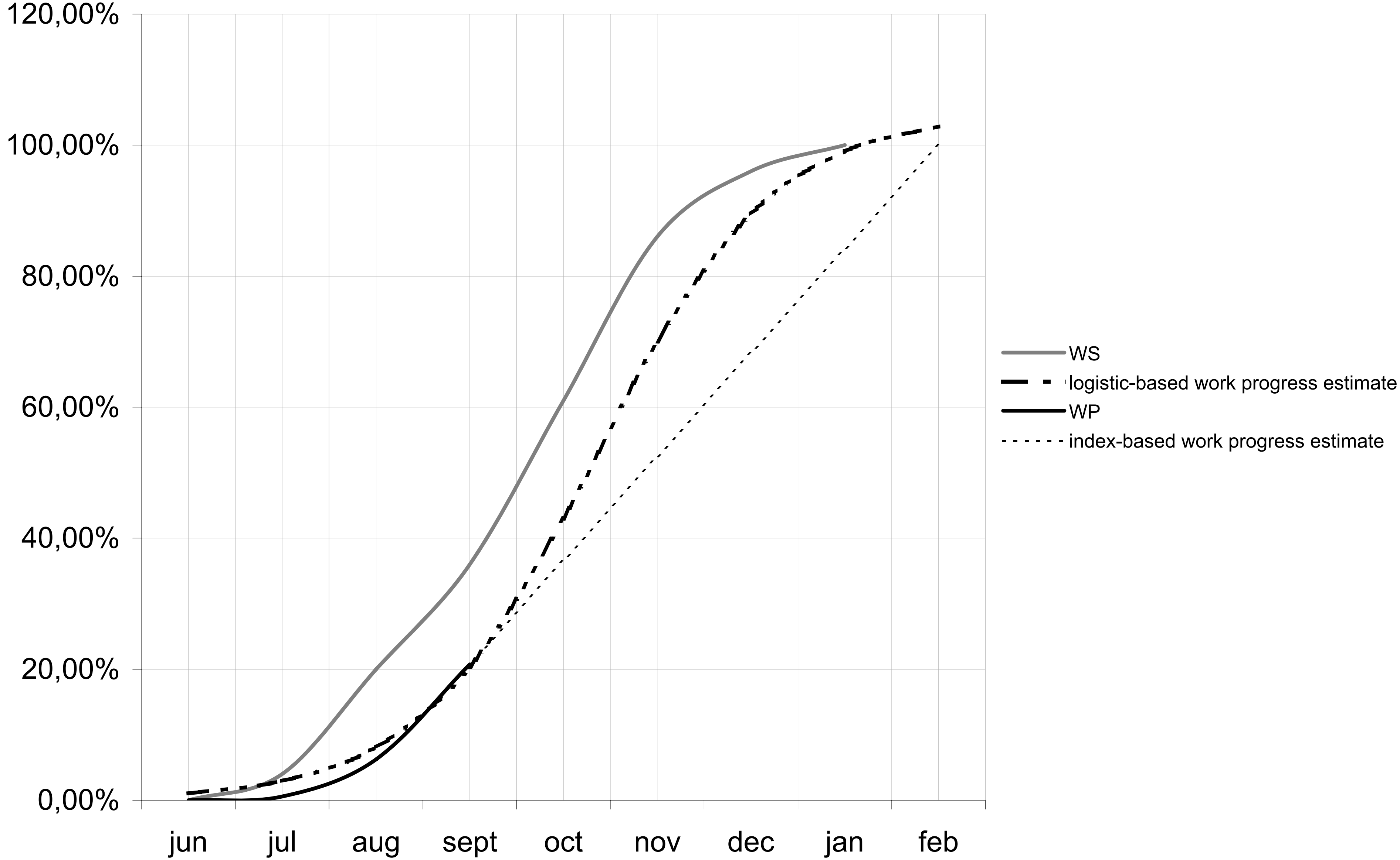
Budget € **67.947,87**

WI	w	WI	%	WI	%	WI	%	WI	%	WI	%
a	61%	a	100%	a	100%	a	100%	a	100%	a	100%
b	17%	b	100%	b	100%	b	100%	b	0%	b	0%
c	17%	c	100%	c	100%	c	100%	c	0%	c	0%
z	5%	z	0%	z	0%	z	0%	z	0%	z	0%
% progress (loft)			95%		95%		95%		61%		61%
% progress (work package)			81%								

AREA	**001**	**002**	**003**	**004**	**005**	**006**	**007**	**008**	**009**	**010**	**011**	**012**	**013**	**014**	**015**	**016**	**017**	**018**	**019**
Work scheduled	20%	36%	36%	36%	37%	36%	20%	20%	60%	59%	36%	36%	36%	43%	20%	20%	20%	20%	20%
Work performed	57%	10%	27%	3%	3%	24%	1%	49%	57%	78%	16%	18%	4%	6%	2%	2%	0%	0%	14%




1,1
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
jun
jul
aug
sept
oct
nov
dec
jan
CPI
SPI


120,00%
100,00%
80,00%
60,00%
40,00%
20,00%
0,00%
jun
jul
aug
sept
oct
nov
dec
jan
feb
WS
logistic-based work progress estimate
WP
index-based work progress estimate

CBS code					Name	Specifications (summary)	Quantity	Unit Price	Subtotal
WBS code				**Work element** Contract ID					
Area	Category	Item	Activity						
002-	001-	001-	002-	OE-AP-005	Demolition of ceilings	Demolition of plaster, fiber and wood ceilings; removal of supporting structures, trusses and hangers. This includes transportation and waste disposal to the dumping ground.	1,250 sq.m	7.56 €	9,450.00 €

Work items	a	b	c	d	e	Total
Budget (€)	356,167.68	16,835.52	713,993.70	746,033.74	10,463.42	1,843,494.06
Weight	18.4%	0.9%	36.8%	38.4%	0.5%	95%

	06 jun	07 jul	08 aug	09 sept	10 oct	11 nov	12 dec	01 jan
BCWS	€ 0.00	€ 370,220.00	€ 2,080,080.00	€ 5,730,920.00	€ 9,625,720.00	€ 16,050,000.00	€ 19,688,000.00	€ 21,400,000.00
%	0.00%	1.73%	9.72%	26.78%	44.98%	75.00%	92.00%	100.00%
ACWP	€ 0.00	€ 535,000.00	€ 2,461,000.00	€ 4,562,480.00	€ 7,468,600.00	€ 11,936,920.00	€ 15,729,000.00	€ 21,913,600.00
%	0.00%	2.50%	11.50%	21.32%	34.90%	55.78%	73.50%	102.40%
BCWP	€ 0.00	€ 124,120.00	€ 1,333,220.00	€ 4,442,640.00	€ 7,201,100.00	€ 11,249,980.00	€ 14,768,140.00	€ 21,400,000.00
%	0.00%	0.58%	6.23%	20.76%	33.65%	52.57%	69.01%	100.00%
CV		-€ 410,880.00	-€ 1,127,780.00	-€ 119,840.00	-€ 267,500.00	-€ 686,940.00	-€ 960,860.00	-€ 513,600.00
CPI		0.232	0.542	0.974	0.964	0.942	0.939	0.977
SV		-€ 246,100.00	-€ 746,860.00	-€ 1,288,280.00	-€ 2,424,620.00	-€ 4,800,020.00	-€ 4,919,860.00	€ 0.00
SPI		0.335	0.641	0.775	0.748	0.701	0.750	1.000
EAC (index-based)		€ 92,241,379.31	€ 39,502,407.70	€ 21,977,263.97	€ 22,194,947.99	€ 22,706,714.86	€ 22,792,348.93	€ 21,913,600.00
Cost overrun		-€ 70,841,379.31	-€ 18,102,407.70	-€ 577,263.97	-€ 794,947.99	-€ 1,306,714.86	-€ 1,392,348.93	-€ 513,600.00
%		331.03%	84.59%	2.70%	3.71%	6.11%	6.51%	2.40%
TEAC (index-based)		508	268	227	229	250	210	189
Time overrun		-319	-79	-38	-40	-61	-21	0
%		168.67%	41.70%	20.33%	21.37%	32.51%	11.02%	0.00%