

# Engineering progress measured on CAD 3D model data rather than drawings

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**Abstract.** Current CAD/PLM technology is finally allowing to perform engineering progress evaluation based on the model data rather than on traditional drawings and human subjective estimation. The paper illustrates the applied method, the requirements posed on the CAD/PLM solution to guarantee the applicability and a solution already available on the market. The real case study shows an example of the design progress and costs evaluation based on “bulk items by weight” that well fits the case of Work Packages dealing with the hull structure in the shipbuilding industry.

**Keywords.** CAD, Project Control, Engineering Progress, Cost Assessment.

## 1. Introduction

The purpose of this paper is to illustrate a solution that allows to quickly control the progress in the design of any kind of process, power or marine plants, including ships prototype, sister-ships or semi-repeated ships. The evaluation of the executed job, based on objective and standardized criteria can be extended to the cost assessments in terms of engineering hours spent in design and in the creation of deliverables e.g. drawings and reports which content is generally described in the standard procurement specifications.

Thanks to the unique CAD model database and the centralized Project Control tool the described evaluation method is applicable to internal as well as to external (subcontracted) design engineering activities [1].

The evaluation of the executed job compared to the expected final results is called progress. The progress is expressing, in numbers/percentage, the evolution of the 3D model i.e. it's reached maturity level at pre-defined check-points. At the check-points (Milestones) the requirement is not only the creation of a number of specific business objects (components) but also obtaining an approval status while reaching certain characteristics e.g. different representation levels and a growing number of non-graphical attributes showing the achievement of pre-defined stages.

In order to express the engineering progress of all the outfitting components the following formula is applied:

$$Progress = EarnedValue / PlannedValue = \Sigma (Ev * Wt) / \Sigma (Pv * Wt) \quad (1)$$

where:

*Ev* is the earned value of each measured object

$W_t$  is the object type “figurative” weight

$P_v$  is the planned number of objects for each type of object

Assuming that the evolution of the CAD 3D model from scratch to the “ready-for-production” might be framed by the following 4 typical milestones and sample maturity percentage: Issue for Approval (25%), for Design (60%), for Procurement (80%) and finally Issue for Construction (100%).

Object Type		→ Tagged Object							
Object Type Weight → 3									
Property Weights	40%	Item Number	20%	Item Number	20%	Item Number	10%	Item Number	
	30%	Description	20%	Description	15%	Description	10%	Description	
	30%	Property #3	20%	Property #3	15%	Property #3	10%	Property #3	
			20%	Property #4	15%	Property #4	10%	Property #4	
			20%	Property #5	15%	Property #5	10%	Property #5	
					10%	Property #6	10%	Property #6	
					10%	Property #7	20%	Property #7	
							20%	Property #8	
Max Earned Value		25%		60%		80%		100%	
Milestones		Milestone 1 e.g. Issued for Approval		Milestone 2 e.g. Issued for Design		Milestone 3 e.g. Issued for Procurement		Milestone 4 e.g. Issued for Construction	

Figure 1. Template milestones and values applied for tagged outfitting components

The engineering progress calculation is based on the sum of the maturity of each of the considered objects in the 3D model e.g. assuming that the maximum contribution in the Earned Value for the milestone 2 is 60%; if one of the 2 properties additionally requested for this milestone has not been populated and each of them “weights” by 20% the resulting Earned Value will be 80% out of the maximum reachable 60% i.e. 0.48 of the target.

The structural components are treated as “bulk” in spite of the fact that each of them, individually, is evolving through clearly defined stages: structural components are typically created during the basic design stage, these are modified during the detailing phase and finalized during the manufacturing/construction phase. The progress for an Engineering Work Package that contains “bulk items by weight” as in the hull structure or “bulk items by volume” as in the building concrete, can be calculated using the same formula where instead of the number of components (business objects) the quantities are expressed in [Kg] or [m<sup>3</sup>].

The case-study considers only hull design activities; typical outfitting/plant activities like equipment layout, pipe and duct routing or electrical cable routing have been left out for future analyses.

In the configuration of the proposed solution the 3D CAD tool can easily extract and share with the Project Control tool the data relevant to all the objects that are composing an area of the plant or a section/block of a ship and evaluate the progress and the engineering costs following the formulas that fit the nature of the objects as well as the specificity of the business case.

## 2. The CAD and the Project Control integration

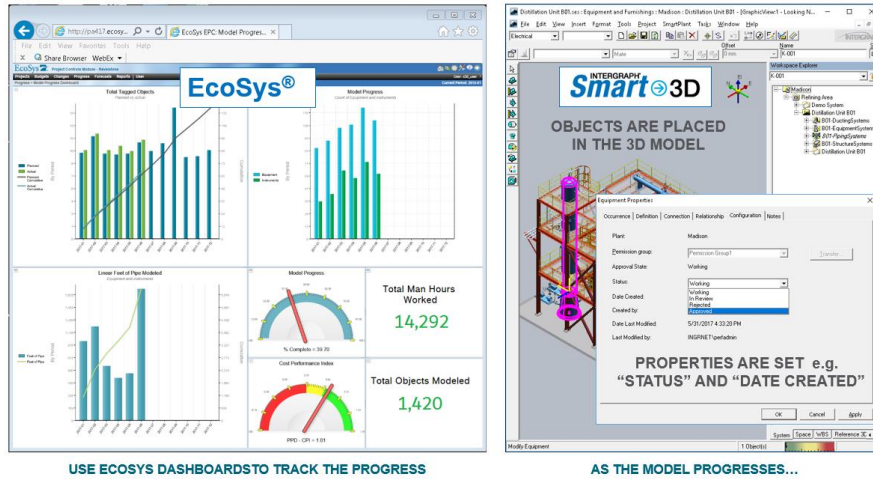


Figure 2. The Project Control and the CAD 3D tool

The current level of integration between the 3D CAD and the Project Control tool is the result of incremental development steps that are including also other applications of the comprehensive SmartYard<sup>®</sup> solution (see the updates of the 3D model (n.9) and the corresponding evaluation of the progress (n.22) in Figure. 3. beside Smart<sup>®</sup>3D and EcoSys<sup>®</sup> integration there is also the material management (Smart Materials), the construction (Smart Construction) and the third party planning tool (Primavera<sup>®</sup>).

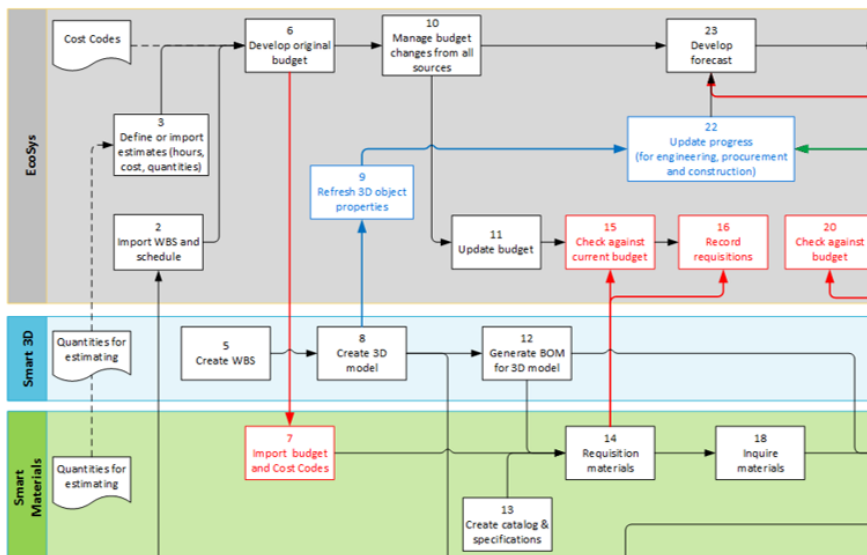


Figure 3. Portion of data flow diagram including the CAD and Project Control streams.

The integration between Smart<sup>®</sup>3D and EcoSys<sup>®</sup> allows to share relevant CAD data in a structured way [5] so that the system (PBS) or the assembly hierarchy (WBS) used for the design process maps the CBS in EcoSys<sup>®</sup> that is built on Cost Control Levels.

The latest steps in the development of the integrated solution have introduced dedicated Web APIs that enable Project Control customized applications and reports to run in traditional as well as in the Cloud system architecture.

The most important consequence of such a tight integration between the CAD and the Project Control tool is the possibility to perform Project Control activities by the interested management profiles with the necessary discretion and the desired frequency without requesting any overhead labour to the designers or other CAD system operators.

### 3. The case-study

The purpose of the case-study was to validate on-site the proposed method and define the formulas to express numerically the engineering progress.

Together with the Customer it has been decided to focus on a discipline that is considered critical and to keep the analysis as simple as possible, therefore the scope of the case-study was limited to:

- Hull structure of already modelled blocks of a cruise ship
- Consider all the hull structure as of the same object type i.e. no differentiation between primary and secondary structure as suggested in other cases (plants)
- The use of MS Excel sheets for the data transfer between the 2 tools in use i.e. an interface to prove the concept rather than an integration as it should be put in place in production.

Smart<sup>®</sup>3D has been the only CAD 3D tool used to create all the structural objects and to modify them during the engineering process adding data (properties) important for the manufacturing and the construction. Regardless of the approval status and the maturity level with Smart<sup>®</sup>3D it is always possible to extract the Weight and the CoG of an aggregation of components (assembly) then, to the need, Smart<sup>®</sup>3D can discriminate (filter) the report generation of structural objects by type, by time stamp, by author and by any other associated attributes. The generated outputs are MS Excel sheets.

For the case-study a report including a subset of the considered areas of the hull, has been used to transfer the data (weight/lotto) from the CAD to the Project Control tool. In EcoSys<sup>®</sup>, to express the engineering progress of the hull structure the used formula is equivalent to (1) where:

$E_v$  is the earned value of each weighted structural object

$W_t$  is the physical weight of each structural object

$P_v$  is the planned weight of the completed "lotto"

The progress might be roughly expressed by the ratio between the weight of all the structural components belonging to a "lotto" and the expected (total) weight of the completed "lotto".

The project gets by default a progressive number e.g. PRJ-000032; this was good enough for the case-study although the displayed name in the table should be substituted with an Alternative ID fully matching the analyzed ship/build.

EcoSys

Collaborations Portfolios Projects Contracts Budgets Changes Progress Forecasts Reports User Configure

3D Progress > 3D Actual

\* Project: PRJ-000032 - NAVE Test

Actuals Register NAV Log Import Reports

ACTa20A Actuals Summary NAV

Sheet Edit Display Rows

Path ID	Name	Weight Actual [Kg]	Weight Planned [Kg]	Weight % Complete
		1,080,458	1,591,314	
PRJ-000032	NAVE Test	1,080,458	1,591,314	0.00
PRJ-000032.E1	Zona E1	769,630	788,513	0.00
PRJ-000032.E1.E1A	Section E1A	267,968	269,580	0.00
PRJ-000032.E1.E1A.E014	Lotto E014	267,968	269,580	99.40
PRJ-000032.E1.E1B	Section E1B	253,157	264,888	0.00
PRJ-000032.E1.E1B.E015	Lotto E015	253,157	264,888	95.57
PRJ-000032.E1.E1C	Section E1C	248,505	254,045	0.00
PRJ-000032.E1.E1C.E064	Lotto E064	134,549	133,338	100.91
PRJ-000032.E1.E1C.E065	Lotto E065	113,956	120,707	94.41
PRJ-000032.V1	Zona V1	212,317	511,181	0.00
PRJ-000032.V1.V1B	Section V1B	122,963	183,292	0.00
PRJ-000032.V1.V1B.V115	Lotto V115	62,434	62,775	99.46

Rows 1 - 29 of 29 Show All Page Size 20

**Figure 4.** Progress evaluation based on Weight Complete.

In addition to the progress linked directly to the weight of the “lotto”, thanks to an existing internal Fincantieri document/tool [2] aiming to estimate the number of engineering hours necessary to develop the production documentation for every structural block, the case-study entered also the area of the labour/cost assessment.

The internal document contains a series of parameters and coefficients that allow to correlate the engineering hours to the weight of the involved structure corrected according to the size and type of vessel or area with a homogeneous technical content. The data refer to cruise ships or passenger ferries. The document illustrates the metrics and drivers, made on a historical basis, to be used for the evaluation in hours of the coordination and executive design activities related to the hull structure. The coefficient K1 reflects the size of the ship i.e. the complexity/density of its structure. The coefficient K2 has been introduced in order to define the areas with homogeneous content in structural terms and therefore cost per unit of weight, said parameter has been diversified by ship area. The coefficient K3 (optional) might be used in order to apply a corrective factor to a specific “lotto” within a homogenous structural area; default value is 1. The above parameters and coefficients (Kn) are continuously refined following their application to real cases.

In the case-study both the expected weight of each “lotto” and the corrective coefficients used for the cost/labor assessment are passed together to EcoSys® with a spreadsheet like in Figure 5.

Path ID	ID	Name	Type	Parent Path ID	Cost Control Level	K1 Factor	K2 Factor	K3 Factor	Weight Planned [Kg]
PRJ-000032.V1.V1C.V216	V216	Lotto V216	WBS	PRJ-000032.V1.V1C	Yes	1.0	3.5	1.0	47,804
PRJ-000032.V1.V1C.V166	V166	Lotto V166	WBS	PRJ-000032.V1.V1C	Yes	1.0	3.5	1.0	49,776
PRJ-000032.V1.V1C.V116	V116	Lotto V116	WBS	PRJ-000032.V1.V1C	Yes	1.0	3.5	1.0	53,743
PRJ-000032.V1.V1B.V215	V215	Lotto V215	WBS	PRJ-000032.V1.V1B	Yes	1.0	3.5	1.0	58,130
PRJ-000032.V1.V1B.V165	V165	Lotto V165	WBS	PRJ-000032.V1.V1B	Yes	1.0	3.5	1.0	62,387
PRJ-000032.V1.V1B.V115	V115	Lotto V115	WBS	PRJ-000032.V1.V1B	Yes	1.0	3.5	1.0	62,775
PRJ-000032.V1.V1A.V214	V214	Lotto V214	WBS	PRJ-000032.V1.V1A	Yes	1.0	3.5	1.0	50,404
PRJ-000032.V1.V1A.V164	V164	Lotto V164	WBS	PRJ-000032.V1.V1A	Yes	1.0	3.5	1.0	58,901
PRJ-000032.V1.V1A.V114	V114	Lotto V114	WBS	PRJ-000032.V1.V1A	Yes	1.0	3.5	1.0	67,261
PRJ-000032.H1.H1.H223	H223	Lotto H223	WBS	PRJ-000032.H1.H1	Yes	1.0	4.5	1.0	40,719
PRJ-000032.H1.H1.H222	H222	Lotto H222	WBS	PRJ-000032.H1.H1	Yes	1.0	4.5	1.0	73,243
PRJ-000032.H1.H1.H173	H173	Lotto H173	WBS	PRJ-000032.H1.H1	Yes	1.0	4.5	1.0	36,209
PRJ-000032.H1.H1.H172	H172	Lotto H172	WBS	PRJ-000032.H1.H1	Yes	1.0	4.5	1.0	60,723
PRJ-000032.H1.H1.H124	H124	Lotto H124	WBS	PRJ-000032.H1.H1	Yes	1.0	4.5	1.0	80,726
PRJ-000032.E1.E1C.E065	E065	Lotto E065	WBS	PRJ-000032.E1.E1C	Yes	1.0	4.0	1.0	120,707
PRJ-000032.E1.E1C.E064	E064	Lotto E064	WBS	PRJ-000032.E1.E1C	Yes	1.0	4.0	1.0	133,338
PRJ-000032.E1.E1B.E015	E015	Lotto E015	WBS	PRJ-000032.E1.E1B	Yes	1.0	4.0	1.0	264,888
PRJ-000032.E1.E1A.E014	E014	Lotto E014	WBS	PRJ-000032.E1.E1A	Yes	1.0	4.0	1.0	269,580

Figure 5. Planned Weight and related Kn coefficients by 'lotto'

Figure 6. to illustrate the planned and the actual weight and the correlated engineering hours for the selected lotto V114:

The screenshot shows the EcoSys software interface. At the top, there is a navigation bar with tabs: Collaborations, Portfolios, Projects, Contracts, Budgets, Changes, Progress, Forecasts, Reports, User, and Configure. Below this, the project path is shown as '3D Progress > 3D Actual' and the project name is 'PRJ-000032 - NAVE Test'. The main section is titled 'Actuals Register NAV' and contains a table with the following columns: Path ID, Name, Eng Hours, Weight Actual [Kg], Weight Planned [Kg], and Weight % Complete. The table lists various path IDs, with 'PRJ-000032.V1.V1A.V114' (Lotto V114) highlighted in orange, showing 238 engineering hours and a weight of 67,261 kg. Below this, there is a section for 'ACTa25 Actuals Register Tabs Staging NAV' with a sub-section for 'WBS: V114 - Lotto V114'. This section contains a table with columns: WBS Path ID, Cost Account ID, Quantity, UOM, Date, and Eng Hours. The table shows a single entry for 'PRJ-000032.V1.V1A.V114' with a quantity of 67,897.0 kg and 238 engineering hours.

Path ID	Name	Eng Hours	Weight Actual [Kg]	Weight Planned [Kg]	Weight % Complete
		4,265	1,080,458	1,591,314	
PRJ-000032.V1.V1A	Section V1A	213	89,354	176,566	0.00
PRJ-000032.V1.V1A.V214	Lotto V214	0	0	50,404	0.00
PRJ-000032.V1.V1A.V164	Lotto V164	75	21,457	58,901	36.43
PRJ-000032.V1.V1A.V114	Lotto V114	238	67,897	67,261	100.95
PRJ-000032.H1	Zona H1	443	98,511	291,620	0.00
PRJ-000032.H1.H1	Section H1	443	98,511	291,620	0.00

WBS Path ID	Cost Account ID	Quantity	UOM	Date	Eng Hours
		67,897.0			238
PRJ-000032.V1.V1A.V114	Default	67,897.0	Kg	04/04/2018	238

Figure 6. Engineering hours spent on the lotto V114

#### 4. Conclusions

The weight of the modelled structure has been identified as the most satisfactory parameter to evaluate the progress in the engineering of the hull structure, nonetheless, even without differentiating the structure by type (e.g. primary and secondary) the physical weight of the components should be corrected by a factor that is expressing the maturity level of the components/objects in a way analogous to the “property weights” used for the outfitting components described in Figure 1.

The possibility to express numerically the maturity level of the components and the implied effort necessary to generate the deliverables at certain engineering stage is probably representing the biggest difference compared to the traditional evaluation of the progress when dealing with the hull structure. In the traditional design an object is considered as defined when it is detailed on a drawing; then its weight it is also calculated and reported. In Smart<sup>®</sup>3D the weight is there (in the database) since the earliest definition of the object in Molded Forms [3]. The weight is subsequently refined introducing cuts and holes during the Structural Detailing stage and, after that, in the Manufacturing stage, additional effort (hours) is required to add production and construction information to objects that are not changing in terms of physical weight any more [4].

Considering the target to evaluate “in hours the coordination and executive design activities” [2] necessary for certain hull zone or block, Figure 7. illustrates the effort along the engineering process and should be used in the evaluation of the progress.

Object Type → Bulk Hull Structure		Object Type Weight → 1		Object Type Weight → 1		Object Type Weight → 1	
Property Weights	40%	Item Weight	20%	Item Weight	20%	Item Weight	20%
	20%	Description	10%	Description	10%	Description	10%
	40%	Molded Forms Properties	20%	Molded Forms Properties	20%	Molded Forms Properties	20%
		Detailed Design Properties	50%	Detailed Design Properties	20%	Detailed Design Properties	20%
				30%	Manufacturing Properties	15%	Manufacturing Properties
						15%	Construction Properties
Max Earned Value	25%		60%		80%		100%
Milestones	Milestone 1 e.g. Molded Forms Approval		Milestone 2 e.g. Detail Design Approval		Milestone 3 e.g. Manufacturing Approval		Milestone 4 e.g. Construction Approval

Figure 7. Template milestones and values applied for hull structure

The Max Earned Value per stage/milestone has been aligned with the outfitting disciplines (the 25, 60, 80 and 100%). These values can be easily refined taking into account the actual spent hours per stage/milestone. Milestone 2 is supposed to carry 1/3 of the overall effort in spite of the automation in detailing and drawing generation; this because the stage should be inclusive of some “manual” Struct Detailing and all the Molded Forms re-modelling due to the co-ordination with the outfitting disciplines.

The analysis of the available data (purely indicative) shows that more than 2/3 of the weight of the hull structure for a zone/block can be defined during the first week of the design work and that 4/5 of the estimated weight can be reached in the subsequent week.

Applying the suggested ‘weighted’ formula (1) for the progress we should obtain the following after the 2<sup>nd</sup> week of design work:

$$(ActualHull / PlannedHull) * (MaxEarnedValue) \text{ e.g. } 45[t]/55[t] * 0.25 \sim 20\%$$

A couple of weeks of modelling hull structure in Molded Forms [3] seems enough for the validation of the co-ordination and also for the fine tuning of the estimated weights of zones/blocks in case of prototypes ships. To be confirmed by the practice, of course.

Anyhow the case-study validated the idea of integrated 3D CAD and Project Control tools each performing within respective domain while providing a transparent unique solution where the CAD is giving real-time information about the content and the status of the 3D model (business object quantities with related maturity levels) while the Project Control tool is providing continuous visibility to power business users on project earned values with respect to budgeted and/or planned values just through its configuration that includes the use of custom formulas to evaluate the engineering progress.

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