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EARNED VALUE MANAGEMENT USED TO MONITOR THE PROJECT COSTS OF BALLAST SYSTEM FABRICATION AND INSTALLATION ON A CARGO SHIP

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ABSTRACT

The development of projects in the naval field is of crucial importance for the industry. Their success depends on how their costs and duration are managed. The study aims to present how naval projects can be monitored using Earned Value Management (EVM), a technique used to evaluate their performance from the point of view of costs. The Earned Value analysis has been applied to the manufacture and installation of a ballast system on a cargo ship. The obtained results have demonstrated that savings are achieved and the works are delayed compared to the plan.

Keywords: Earned Value Management, project performance, ACWP, BCWP, BCWS

1. INTRODUCTION

Due to the frequent failure of projects resulting from exceeding established budgets and/or planned deadlines, it is necessary to take action to monitor the progress of the activities within the projects. All the activities carried out for reporting project costs, risks, and project control increase the importance of project management activities.

Earned Value Management (EVM) is a new control technique used in project management, which measures the performance of the work performed [1]. This method predicts the final cost and duration of the project by comparing the work performed with the planned one, warning in time of the appearance of any problem so that it can be solved before it becomes critical [1], [3].

Regardless of the project's scope, the method provides the project manager with early visibility into cost and schedule deviations.

Even if the method has undergone a series of updates over time, its purpose is to have a formal version of the "Earned Value" notion, used for project monitoring and control [4].

The acquired value (EV) of a work executed within the project is the estimated cost of that work at the time of defining the budget and is called the planned cost of the work performed (BCWP). This estimated cost is calculated for the works carried out, at a given moment, by adding up the value of each work within the project, taking into account the percentage in which these works are executed at that time [6].

The paper presents how the EVM method is applied for cost monitoring in the ballast system fabrication and installation project on a cargo ship specialized in transporting modules on the main deck weighing up to 2,000 tons.

2. RESEARCH METHOD

To apply the EVM method in a project and to evaluate its performance, it is necessary to define the terms used within this method: the

Earned value (EV) or BCWP, the actual cost of the executed works (ACWP), and the budgeted cost of the scheduled works (BCWS) or planned value (PV).

If the EV value is known when the budget has been defined, and the costs of each work in the project have been estimated, the ACWP is determined by collecting real data on the costs of labor and materials used. By comparing the BCWP with the ACWP, the cost variation (CV) is obtained, which shows whether savings have been achieved compared to the initial budget or whether the actual costs exceeded the planned costs in the project.

BCWS costs are obtained, taking into account the costs from the estimate tables, the date on which the works are scheduled for execution, using the initially established work schedule and the expenditure profile for each work during its execution.

To determine whether the works in the project are ahead or behind schedule, the BCWP is compared with the BCWS, resulting in the schedule variance (SV), which measures in money the progress of the execution of the works compared to the initial planning (Lipke, 2023).

At the end of the project, the BCWS value coincides with the value estimated in the project budget (PB).

The total estimated cost at completion (ECAC) can also be calculated under two assumptions:

-ECAC=PB-CV, when the remaining works are carried out according to the budget;

-ECAC=PB X (ACWP/BCWP), when the remaining works are carried out with the same costs as those already completed;

Another important indicator of this method is cost to complete (CTC), which refers to the estimated cost of the unexecuted works at the time of project monitoring, calculated as the difference between the completed costs (ACWP) and ECAC [7].

Figure 1 shows the terms used in the EVM. method.

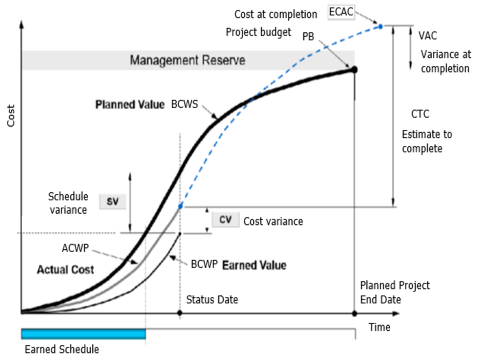

Figure 1 Basic terms used in the EVM method (adapted from Earned Value Management: APM Guidelines (2008))

The estimated project completion date (ECD) can be calculated using two interpretations [2]:

-the case in which all the works remaining until the end of the project are carried out according to the initial planning (ECD=ECD0 +/- the time gap compared to the planning);

-the case in which all the works remaining until the end of the project have the same delay as the works already completed (ECD=ECD0 x BCWS/BCWP).

3. THE BALLAST WATER SYSTEM

The ballast water system was designed to control trim, draught, stability, and stress applied to the ship structure. It allows the transferring of ballast water between ballast water tanks and the handling of ballast water introduced from the sea. Ballast pumps have suction connected to crossover tanks. All ballast tanks are automatized with level sensors and valves remote operated and controlled from 2 control points, a bridge, and an engine control room. The system was designed to be operated by one ballast pump and one ballast treatment unit, according to the authorities' requirements, because ballast water can contain aquatic organisms, which introduced into the sea may create a hazard to the environment.

Ballast water tanks are grouped into two identical systems, one system for portside and one for starboard. Each of them is connected to a ballast water treatment unit. For emergency cases, one backup pump is arranged, which can operate both systems portside and starboard. These two systems are connected to the crossovers by the pumps capable of transferring ballast water from and to sea and between the tank groups.

Pumps for ballast system: • Two main pumps with a nominal capacity of 1000 m^3/h at a 3 bar pressure each of them • One backup pump with a nominal capacity of 500 m^3/h • Two ballast treatment pump units with a nominal capacity of 100 m^3 /h each of them. Valves were designed as follows: • Valves on ballast main pumps • Throttle valves, one for each tank group – for overboard discharge, double controlled automatic and manually by crew operator • Tank valves – presented on each tank and can be automatically or manually controlled by crew operator • Branch valves (another that mentioned below) automatically controlled.

Ballast water management system means all systems that process ballast water including ballast water treatment equipment, monitoring equipment, and sampling facilities. Using this system, we avoid the discharge of harmful organisms within ballast water and sediments during the voyage. The ballast water treatment units were designed with two units, one for each ballast main pump.

4. CASE STUDY

To apply the EVM method in the case of the manufacturing project and installation of the ballast system on a cargo ship, with dimensions Lmax=124m, Lpp=119m, B=17m, D=6m, d=3.2 m, displacement=5315 t, the procedure was as follows:

- the costs for the design activity were determined (Table 1)

Design activity consists of:

• 3D routing model for ballast installation according to system diagram
• Fitting list and ordering – supply list with valves, filters, actuators, sensors
• Material list for manufacturing - tees, elbows, reductions, pipes, flanges
• Class and owner checking and approval drawing
• Alteration sheets and modifications requested by the owner during the project
• Phase division for mounting according to project stage

Table 1 Costs for the design activity

Design costs				
Engineer involved	Salary level		Total cost (RON)	Total costs (euro)
4	D	4530	4528	1006.22
2	E	4820	2408	535.11
3	F	5460	4092	909.33
1	G	5940	1484	329.77
		Total	12512	2780.44

-costs for the prefabrication activity (Table 2 and Table 3)

The prefabrication activity consists in:

• Material preparation with list received from the technical department.
• Cutting and assembling of pipes spools with fittings (reductions, tee's, elbows, plugs, flanges, sleeves, free flanges);
• Welding the above-mentioned pipes and fittings;
• NDT Controls (non-destructible control) – for pipes with special requirements by class (see pipes class I and II) – shell connection pipes, high pressure and temperature pipes – for example, steam systems which are working at approx. 200 degrees.
• Treatment application – can be: galvanized, painted, passivation, oiling

As a medium value for manufacturing cost/pipe, we can consider 4.3h/piece.

Following this value, the estimated hours for manufacturing scope of work pipes can be analyzed in Table 2 and Table 3.

a) Employers in prefabrication costs

Table 2 The costs for man-hours manufacturing activity

Manufacturing man-hours planned		
Total pcs to be manufactured	795	pcs
Estimated hours/piece manufactured	4.3	h
Planned hours for manufacturing	3418.5	h
Man-hour cost	18.7	EUR
Planned total man-hours costs	**63926**	**EUR**
Real cost for man-hours used for manufacturing		
Employers involved	38	people
Days	12	days
Hours/day	8	hours
Total hours used	3648	h
Man-hour cost	19	EUR
Total man-hours used costs	**69312**	**EUR**

b) Material costs for prefabrication

Table 3 The costs for material used for prefabrication

Material costs for manufacturing				
Nr.	Types of pipe	Price euro /kg	weight (kg)	Total price (euro)
1	DN 50	0.96	2210	2121.6
2	DN 65	0.96	2228	2138.88
3	DN 80	0.96	754	723.84
4	DN 100	0.96	1479	1419.84
5	DN 125	1.17	2725	3188.25
6	DN 150	1.17	7944	9294.48
7	DN 200	1.22	8759	10685.98
8	DN 250	1.22	8426	10279.72
		TOTAL	**34525**	**39852.59**

-installation costs (Table 4)

Mounting activity consists of:

- Fixing the pipes on the montage position
- Manufacturing supports and clamping the pipes
- Mounting of fittings – valves, filters, gasket, accessories
- Welding of pipe connection (sleeves)
- Welding of supports
- Technical delivery and pressure test requested by authority (class and owner).

The mounting activity must fulfill technical and welding international standards required by authorities and the owner. All pipefitters and welders must be qualified and trained according to the specified job. Welders licenses must be valid and according to the applied procedure for different joints (butt welded joint for pipes class 1 and 2, sleeve joint) and different materials (carbon steel, stainless steel, conifer pipes, stainless steel duplex, etc.).

As a medium value for mounting the above-mentioned activities cost/pipe, we can consider 7.4 hours/piece mounted with a medium weight of piece 24 kg/pcs.

Table 4 Man-hour budgeting according to pipes medium weight

Budget estimation for mounting pipes		
Total weight	34525.0	kg
Total no. of pcs to be installed	795.0	pcs
Medium weight of 1 pipe	43.4	kg/pcs
Initial hours budget	7.4	h/pcs
25% from initial budget	1.9	h
Updated hours / pcs for medium weight 43 kg/pcs	9.3	h/pcs

Since the ballast system, in our case, contains 795 pcs and a total weight of 34.525 kg, it results in a medium weight of a piece with 43 kg/pcs. For that reason, the planning and estimators department decided to increase the budget for mounting by 25% and we obtained a budget of 9.3 hours/piece mounted, and the activities distribution budget is detailed in Table 5.

Table 5 Man-hours distribution for mounting activities

Mounting budget/pcs	9.3h
Mounting - pipe fixing, supports manufacturing, valves and fitting mounting 60% from budget	5.58 h
Welding - 28% from budget	2.60 h
Technical delivery and pressure test - 12% from budget	1.11 h

An important cost added to the building of pipe systems represents the cost of armatures (valves manually operated, valves remote controlled, sensors, coupling and connection with different equipment, remote transmitters for pressure and levels, exemplified for ballast system in Table 6.

Table 6 Armatures costs for ballast installation

Crt.	Armature type	€/pcs	No pcs.	Cost (euro)
1	Butterfly valve LUG TYPE	1615	28	45220
2	Globe stop-Check Valve	46	6	276
3	Flanged ball valve	81	9	729
4	Butterfly valve with actuator	1876	26	48776
5	Butterfly valve with gear	741	14	10374
6	Straight filter	75	3	225
7	Drain box	32	2	64
8	Local Indicator for pressure	135	6	810
9	Hose Coupling to poumps	32	5	160
10	Pressure remote tranmitter	2450	6	14700
11	Rubber Compensator	760	4	3040
			Total	124374

Table 7 presents the total costs for ballast installation.

Table 7 Centralized costs for ballast installation

Total costs for ballast installation	
Design	2,780.44 €
Manufacturing	69,312 €
Material cost for manufacturing	39,852.59 €
Mounting	138,258 €
Armatures costs	124,374 €
Total	**374,577.03 €**

Table 8 presents the costs for manufacturing and mounting.

Table 8 Manufacturing and mounting costs

			Manufacturing		Mounting			Costs (euro)			
Block	Spools [pcs]	Spool weight (kg)	Cutting and assembly (h)	Welding (h)	Mounting (h)	Welding (h)	Technical delivery & pressure test	Material cost (euro)	The workmanship cost manufacturing (euro)	The workmanship cost mounting (euro)	**Total cost (euro)**
BL01	144	3556	402	217	804	375	161	4105	11579	25043	**40727**
BL02	94	3660	263	141	525	245	105	4225	7559	16348	**28131**
BL03	249	16941	696	375	1389	648	278	19555	20022	43304	**82881**
BL04	174	8425	486	262	971	453	194	9725	13991	30260	**53976**
BL05	134	1943	375	202	748	349	150	2243	10775	23304	**36322**
Total	**795**	34525	**2222**	**1196**	**4436**	**2070**	**887**	**39852**	**63926**	**138258**	**242036**

The total cost for manufacturing and installing 795 pipes for the ballast system on a ship with five blocks, as shown in the table above, is 242.036 EUR. Referring solely to the assembly costs, we can consider 138.258 EUR, which was calculated based on the number of hours worked multiplied by the man-hour rate of 18.70 EUR per hour.

Figure 2 presents the Gantt chart for the installation and mounting of the ballast system.

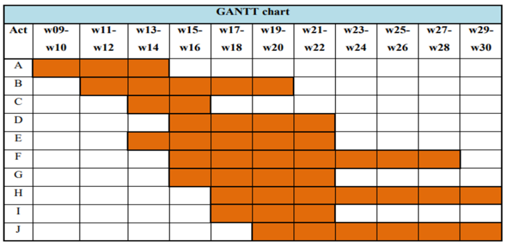

Figure 2 GANTT chart for the installation and mounting of the ballast system

The activities divided by block sections are presented in Table 9.

Table 9 Activities divided into blocks

Block	Activity	Activity description	Start	Finish
Block 1	A	Manufacturing of pipes for block 1 - 144 pcs	w09	w14
	B	Mounting of pipes in block 1 - 144 pcs	w11	w20
Block 2	C	Manufacturing of pipes for block 2 - 94 pcs	w13	w16
	D	Mounting of pipes in block 2 - 94 pcs	w15	w22
Block 3	E	Manufacturing of pipes for block 3 - 249 pcs	w13	w22
	F	Mounting of pipes in block 3 - 249 pcs	w15	w28
Block 4	G	Manufacturing of pipes for block 4 - 174 pcs	w15	w22
	H	Mounting of pipes in block 4 - 174 pcs	w17	w30
Block 5	I	Manufacturing of pipes for block 5 - 134 pcs	w17	w22
	J	Mounting of pipes in block 5 - 134 pcs	w19	w30

Table 10 shows the BCWP, BCWS, and ACWP values based on the weekly calculations.

Table 10 ACWP, BCWP, BCWS values per week

Activity	AC (euro)	EV (euro)	PV (euro)
w12	8965	10009.13	12650.77
w16	35002	40878.79	52754.66
w20	82011	94667	118714
w24	113124	136737.63	164226.80
w28	151567	169996.93	187654.21
w30	-	-	202184.4

The graphic representation of ACWP, BCWP, and BCWS values is shown in Figure 3.

In week 28 (when the project is monitored), the values for CV and SV are:

CV = BCWP - ACWP CV = 169996 – 151567 = 18429 EUR

SV = 169996 – 187654 SV = -17658 EUR

The works are behind schedule, even if savings were made in the project budget.

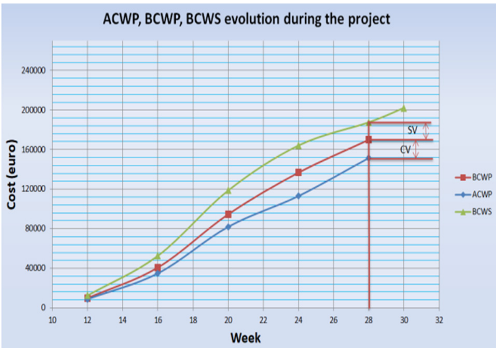

Figure 3 Evolution of the ACWP, BCWP, and BCWS values during the project

The ECD tells us what the deadline for the completion of the works is and is calculated for two assumptions:

1. All work will be completed according to the Gantt chart

$$ECD_1 = ECD_{inițial} \pm GAP$$

$$ECD_1=22+ (187654/169996)$$

$$ECD_1=23.1 \text{ weeks}$$

2. All works remaining to be executed from week 28 until the end of the project suffer a delay compared to the plan.

$$ECD_2 = ECD_{inițial} * \text{delay factor}$$

$$ECD_2 =22 *(187654/169996)$$

$$ECD_2 =24.28 \text{ weeks}$$

ECAC was calculated according to the two hypotheses:

1. The works remaining until the end of the project to be executed will be carried out according to the initial planning

ECAC = 187654.21-18429 =169225.21 EUR

2. The works remaining to be executed until the end of the project will fall under the same costs reported up to now. The second case is more realistic and can be calculated as follows:

ECAC=187654.21 x (151567/169996.93) =167310 EUR

As innovation in Romanian shipyards, we proceed to the pre-outfitting concept. This practice allows us to use our favorite position and space access of units to add outfitting saturation in the primary stage. As a benefit we can mention: easy access from all ways; in this stage, all units prepared for pre-outfitting are rotated with the up to down. All the pipes, which are in the normal position on block stage installation are mounted under the deck and now can be mounted on the "floor" due to the position of the unit.

For the current project, we propose to split out SOW (scope of work) into 2 phases:

- First stage called "pre-outfitting" – unit phase, considered 40% from initial SOW
- Second stage "block" – after lifting of unit and coupling of blocks

A result of this splitting on phases can be remarked in the following new added activities. Initially, there were two activities for each block (manufacturing and mounting). However, after the update, we now account for four activities: manufacturing pipes for the pre-outfitting phase, mounting pipes in pre- outfitting phase, manufacturing pipes for the block phase, and mounting pipes for the block phase.

Due to the unit stage, we have to make pre-outfitting pipes earlier than block pipes.

To demonstrate the efficiency of this practice, we will calculate the cost of 40% of the ballast system mounting during the unit phase. The estimated budget for this activity is 4.6 hours/piece for the technological reason. Also, compared to the old budget, hours for technical delivery and unit phase pressure tests have been eliminated.

Comparing this new strategy, which includes the pre-outfitting phase (Table 11) with the old strategy, a difference can be observed compared to the initial cost of the assembly for 138,258 EUR (Table 8), and the cost of the assembly with the pre-outfitting phase, worth 109,782 EUR, which means a saving of 28,476 EUR.

Table 11 Total cost of montage that includes pre-outfitting

Pre-outfitting strategy	No. pcs	Montage h/pcs	Total hours	Costs (euro)
Pre-outfitting - unit phase	324	4.6	1490.4	27870.48
Block phase	471	9.3	4380.3	81911.61
Total including pre-outfitting	**795**	**13.9**	**5870.7**	**109782.09**
man-hour costs	18.7	euro		

The achieved savings of 28,476 EUR is highlighted in Figure 4.

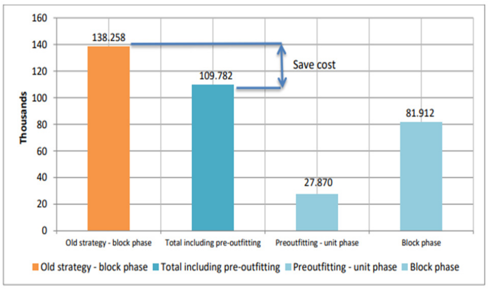

Figure 4 Savings achieved when installing the ballast system by using the pre-outfitting strategy

5. CONCLUSIONS

Earned value is a modern project management technique that, compared to the classical style, uses variables based on continuous data collection. Using this technique, the project management team has a real picture of the project stage, at any moment of its execution.

By monitoring costs, the project manager can allocate additional resources in time to bring the project on schedule and meet the completion deadline.

The earned value calculation for this project in week 28 showed a positive cost variance (less money was spent than planned) but a negative schedule variance (the work is behind schedule).

Using ECD, the project can be completed in approximately 24 weeks instead of 22 weeks and with an ECAC of 167,310 EUR instead of 202,184 EUR, which has been established in the initial budget.

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