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Proposing a novel combination of Earned Value Management and Requirements Management

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Abstract. A wide range of methodologies is used to report progress in projects, all with different strengths and limitations. One such methodology is Earned Value Management. However, both industry and academia highlight substantial issues when applying Earned Value Management on complex projects, creating a need for organizations to seek for ways to improve Earned Value Management. This paper presents the current ways of reporting progress within an organisation using Earned Value Management, its shortcomings, and how combining Earned Value Management with Systems Engineering and Requirements Management may improve the methodology. The proposed solution uses an application of requirement attributes to report previously excluded aspects, such as technical progress, the risk to schedule and budget, and customer concerns.

Introduction

As projects in the oil and gas sector become increasingly complex and the gross margins are under pressure, efficient project planning and control become equally critical for all stakeholders. When the organisation reports on the project's progress, every downstream participant in the supply chain is affected by the status; as a result, reporting must be accurate, inclusive, and unambiguous.

The company, in this paper named Cable Supplier, where the case study was performed, is an international supplier of umbilical systems. The projects that result in umbilical system, as illustrated in Figure 1, are the result of a successful tendering phase. During tendering much of the system is conceptually defined. The overarching system for the umbilical system is an offshore platform for oil & gas production, with the umbilical system being the primary interface between the platform and the subsea infrastructure. These umbilical projects are never identical due to differences in number and nature of interfaces, sub-systems, and technologies. However, they all follow the same project execution model and report their progress using Earned Value Management (EVM).

Management of Cable Supplier identifies the form of EVM currently used as insufficient to present the complete picture of the project's progress. The base of the problem lies with it being mainly based on the completion of documents, which is insufficient to provide a complete and precise picture of the project status. Documents can be rushed without providing all necessary content or stuck in loops of revisions as discussions ramble. Internal progress is left out, and crucial aspects such as technical characteristics, risks, and remaining slack are unaccounted for, decreasing the output value. The Earned Value Management methodology applied seems inadequate as the generated graphs only project a variance between planned expenditure, actual cost, and estimated Earned Value. Ultimately, projects are more than the budget and their schedule, and stakeholders benefit from a complete view of the progress.

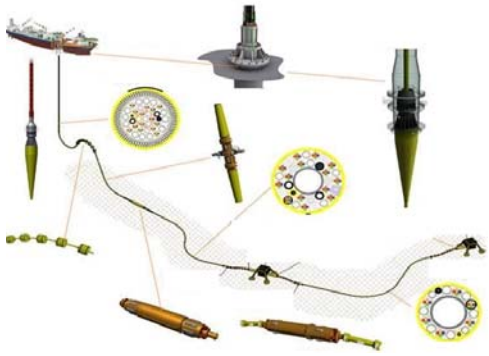


Figure 1. An umbilical system

Problem statement. EVM is a recognised methodology for project monitoring, with identified limitations for complex projects. These limitations call for improvements that may increase precision, degree of coverage, and credibility. Doing so would improve project governance for all stakeholders, both internal and external. A literature review will confirm the limitations and be the foundation for a new methodology, while a case study will determine whether it improves on the abovementioned dimensions.

Hypothesis. Applying a combination of proven alterations of EVM and requirement attributes to the reporting tool used by Cable Supplier would help the methodology circumvent its limitations to precision, degree of coverage, and credibility.

Outline of paper. This paper begins with an introduction to the domain, the organisation, the problem statement, and the hypothesis. Then, the research design is presented, followed by an introduction to Earned Value Management, its limitations, and its application within Cable Supplier. Following this, several possible solutions are outlined, ultimately deciding on one preferred. Lastly, the case study results are presented and used as input to the conclusion.

Research Design

The research is based on qualitative case study methodology, as the research aims to explain and explore a contemporary phenomenon in its real-world context (Yin 2009; Runeson & Höst 2009). In addition to explaining and exploring, the research aims to improve a particular aspect of the phenomenon, as included in Robson's (2002) classification of a case study, cited by Runeson and Höst (2009). The outline of the research is illustrated in Figure 2.

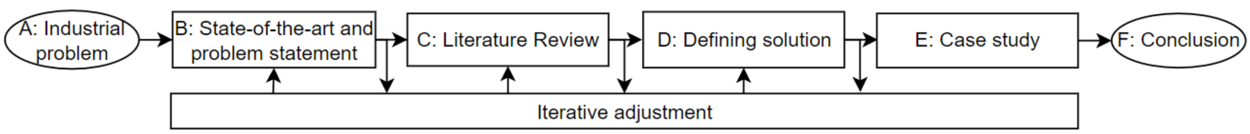


Figure 2. Research Methodology

The research lingered long within the problem definition and state-of-the-art analysis. It was an iterative process of assessing the process for project reporting, the methodology and infrastructure used, the management's concerns, and its relevance to Systems Engineering (SE). As the problem and context became increasingly defined, the literature review was limited to EVM, Requirements management (RM), and its benefits for project control and managing. While this research was conducted, initial interviews were held with stakeholders at Cable Supplier to discuss the findings and their implications. Several methodologies for combining RM and EVM were defined, and a Pugh matrix was used to determine the preferred methodology. Once the solution was determined, reports were produced to prove its application and conclude Phase D. These reports were used throughout the case study to conclude whether the proposed methodology would provide stakeholders with a value exceeding EVM's. The methodology applied during the case study is presented in the chapter named *Analysis of case study,* representing Phase E in the above diagram.

Earned Value Management

It was the U.S government that, who in the 1960s, introduced EVM as an initiative to understand the financial aspects of large acquisition programs (Kwak & Anbari 2012). Today, Project Management Institute (PMI) (2011) declares it consistent with good project management and lists it as one of the discipline's most effective performance measurement and feedback tools. Throughout industry and academia, many are referring to EVM as the "best practice" standard for project controlling (Nkiwane, Meyer & Steyn 2016) and the most advanced technique for integration of schedule and cost (Kim & Ballard 2000). Project Management Institute (2019) describes the methodology behind EVM as a tool for objective measurement of performance and progress and lists it as project management with "the lights on". Furthermore, PMI (2019) states that EVM has a great potential to support and enhance communications and stakeholder management. According to studies, under the right circumstances, one can predict a project's future with a +/-10% deviation 1/5 into the project using EVM (Lipke 2005; Fleming & Koppelman 2000). Thus, EVM is a project management and control tool many consider valuable. Receiving information through accurate forecasts is essential for the project manager (PM) to change negative trends as early as possible by proactively reassessing the project's scope, budget, requirements, or other aspects. Specifically, the EVM methodology allows project management to forecast the project's future and assess the current state so that decisions are made on a more substantial basis, increasing the overall chance of success. The basis of EVM is a comparison of the planned and performed work and the planned and actual cost, thus combining cost, schedule, and "physical progress" into valuable quantitative project performance information (Henderson 2007). It communicates the actual cost compared to the budget in an easy-to-read manner, improving transparency between stakeholders. As a result, Cable Supplier is one of many companies that has adopted EVM as the primary form of project performance measurement. Precisely how the values are calculated, and the values included, differs across the industry.

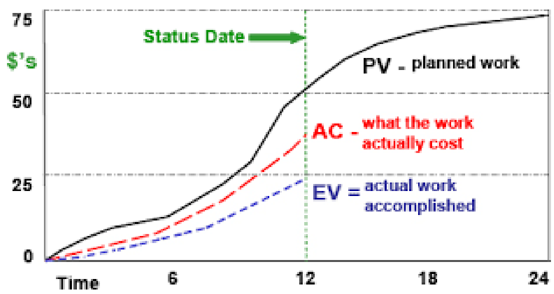


Figure 3. Earned Value Management (EVM)

Cable Supplier utilises only the primary measurements of EVM, illustrated in Figure 3 (Lukas 2012): Actual Cost (AC) – the cost of performing the work related to the project, including overheads, materials, and more. Earned Value (EV) – The value of the tasks completed, often a value set by the contract and the amount refunded by the client. Planned value (PV) – the planned cost for the work yet to be performed. These measurements are then used to calculate the Cost Variance (CV) and Schedule Variance (SV). The cost variance equals EV minus AC, indicating the difference between the budgeted cost and the actual cost of performing the work related to the project scope. Schedule Variance is EV minus PV and measures whether the project sees a negative or positive cash flow.

EVM defines two indexes to assess the abovementioned measurements: Schedule performance index (SPI) = EV/PV and Cost performance index (CPI) = EV/AC. The Schedule Performance Index is used to assess the performance concerning the Schedule. SPI above 1 indicates a project ahead of schedule, and below 1 indicates a project behind schedule. Similarly, the Cost Performance Index measures the performance by comparing the cost and the value created. A CPI below 1 indicates that the project is currently below budget. However, except for reports to Cable Supplier management, all reporting consists of the EV graph only. To summarise and exemplify the core of EVM, one can imagine a project with a BAC of £2000 and the work completed estimated to be 50%. The EV would be £1000 (50% of £2000) – the value created by the work performed.

Limitations of Earned Value Management

Although widely perceived as a powerful tool, as proven by the US Department of Defence requiring EVM to be applied to contracts valued at over $20.000.000 (US Department of Defence - Acquisition 2015), EVM has several limitations and shortcomings (Nizam & Elshannaway 2019). On a higher level, EVM only works as an effective tool when assuming a reliable workflow and that every activity is independent (Kim & Ballard 2000). Especially in environments where LEAN principles are applied, the tasks are often linearly sequenced but still have an interdependent relationship (Nizam & Elshannaway 2019). In environments like these, such as line manufacturing, Task B will rely on a steady flow of goods from Task A to produce as planned. However, suppose the output from task A fluctuates wildly, although still being within the Planned Value. In that case, Task B will struggle to perform according to the PV – but the issue lies with Task A, not task B. EVM will not highlight task A as the problem. This problem also applies to Cable Supplier's document-centric project execution model, although EVM is not explicitly used to highlight specific tasks/documents. Another limitation highlighted is that EVM poorly differentiates between actual value-generating work and non-value-generating work (Nizam & Elshannaway 2019). Although it must be argued that this task comes down to the project planner and manager, it might affect the project execution. The project members may prioritise simple tasks that provide more "earned value" and subsequently achieve higher SPI and CPI, although it might not be the tasks that need to be done at the time; tasks not on the critical path (Nizam & Elshannaway 2019). Likewise, tasks left out of the EVM reports due to difficulties measuring progress might be neglected to increase the earned value and make the project appear better managed. These shortcomings reduce the value of the indices. There is no evidence to confirm or refute that this applies to Cable Supplier. However, issuing documents without all the contents being in place happens regularly while still claiming 75% of their value (ref. above rules of credit).

Likewise, the EV remains when the client rejects the documents and forces Cable Supplier to start over. When the management asks for precision improvement, the dependency on documents is a large part of its reasoning and must be pivotal in future research. Lastly, on a higher level, the upfront planning needed for EVM is substantial, and some consider it a risk management tool. This statement is untrue as the undesired action has already happened when reported in EVM, making future deviations rather than risks (Solomon 2008). Making EVM a better tool for risk management must also be considered in the final solution.

The last perspective taken when looking at the shortcomings of EVM is what it does *not* include. The traditional EVM methodology fails to include quality components, technical performance, or slack measurement (Project Management Institute 2019). Unfortunately, excluding these measures means that the project may be behind schedule for verifying requirements, completing concepts, and meeting specific targets – without it being reflected in the EV. Although the government of the USA requested the DoD to consider the inclusion of quality (Dodson, Defavari & De Carvalho 2015), such measures in EVM has yet to be adapted by the industry. This perspective is where the concerns from Cable Supplier management genuinely lie. Based on the completion of documents, the information currently reported by EVM, schedule, and budget cannot communicate the full project status alone. In order to provide additional value and a fuller view, some form of technical performance must be reported. Choosing the technical performance base measures, objectively reporting them, and thus bridging the gap between SE and EVM are vital to making EVM reliable and accurate (Solomon 2008). These limitations mirror some of the concerns of Cable Suppliers management, being the low degree of coverage: failure to mirror the complete project state, excluding risk and the abundance or absence of slack.

Current application of Earned Value Management in Cable Supplier

The Cable Supplier's current planning and monitoring tools are based on the Work Breakdown Structure (WBS) established during each project's start-up. Key project members collaborate to create a WBS with work packages suitable for future project activities. After that, the planner will create a baseline schedule for the project, containing all the activities needed to fulfil the WBSs. The baseline creation is based on several sources: the master document register (MDR), procurement plan, and manufacturing plan. Then, all the activities in the baseline schedule are weighted based on defined values: number of hours estimated per document, cost of procurement, cost of manufacturing, and more. The team members will assign all used hours and expenses to the different work packages throughout the project. These values are the breakdown of the contractual price, down to activity level, based on the abovementioned rules of credit. The weighting process is crucial for accuracy and is one of the more complex processes when establishing a baseline for EVM project controlling (Kerkhove & Vanhoucke 2016); it is the basis for how the project planner report on progress. Engineering, which accounts for most of the value, is tied to the progress of documents in the MDR. The rules of credit are: 5% of document value is earned when the document is established. Then, sending the document on internal control makes up 70%, while issuing it to the client for review is 5%, receiving comments is 5%, and receiving approval is 15%. The researcher believes that these rules-of credits favour early value achievement, as sending a document on internal control rarely accounts for 70% of the work. The rules of credit for procurement and project administration are similar, spread across the activities of sending a request for quotation, issuing a purchase order, receiving the order, and final inspection. In between issuing the order and receiving the components, the progress is spread linearly between the date of order and the planned receipt date.

EVM and measurement of slack is per today wholly separated. When looking at slack, the belief is that it is positive for the project by providing flexibility and risk mitigation. However, a project having unwarranted slack in the schedule makes the remaining organisation vulnerable to delays elsewhere, as the flexibility is kept within the project and not on an organizational level. Ideally, the remaining slack should be reduced to zero when a project approaches closure, and it is believed that a suitable EVM extension would aid this.

Requirements Management

Solomon (2008) states that EVM can be far more effective as a management tool if its processes are integrated with technical performance and augmented with a rigorous SE process. Furthermore, it is stated that progress against requirements would be a very effective base measure of EV. Altogether, requirements were frequently found as the chosen measure by researchers to assess the system from a technical perspective. Consequently, using requirements for measuring technical performance was deemed a suitable basis for Cable Supplier.

Requirements Management fundamentals

According to SeBok (Faisandier & Roedler 2020), a requirement describes a system or product's necessary operational, functional, or design characteristics or constraints. To document requirements in line with this definition, ISO:15288 (2002) defines the Requirement Analysis Process, which is the process of extracting a defined technical view from the stakeholder requirements. The outcome shall be measurable system requirements that include the system's characteristics and the magnitude needed to satisfy stakeholder requirements. Requirements are thus crucial when deciding what to develop and executing the project, making RM equally important.

RM is used to ensure the alignment of the system and system element requirements with other representations, analyses, and artefacts of the system (Faisandier & Roedler 2020). This continuous process defines, controls, and publishes the baseline requirements for all system levels before recording and maintaining the evolving requirements (ISO/IEC/IEEE 2018). According to ISO 24766 (2009), as cited by Hårstadsveen (2021), RM help align the requirements with the product, making the requirements a good measure within projects of the technical performance. As a result, a coupling with project reporting, using requirements to measure technical performance, would only benefit this process.

An RMS is successful when it aids with understanding the requirements, obtaining commitment, managing changes, and maintaining bi-directional traceability among the requirements and towards the remaining system (Faisandier & Roedler 2020). The system involves several tools and techniques for documenting, tracking, planning, prioritising, and verifying the requirements.

Application of Requirements Management in Cable Supplier

The study performed by Hårstadsveen (2021) concluded that an RMS would be valuable for Cable Supplier, as there are numerous specifications and standards that the engineers must review, often with limited time. The proposed solution was a tailormade system that enabled an existing project document (System Design Basis (SDB)) as a template and database for requirements compiled from all documents. The system includes a linkage between the verification method and all requirements, such as drawings, reports, analyses, and mechanical tests. Many of these methods are currently being reported as part of EVM. Although not implemented yet, it is believed to serve as a good foundation for technical measurement. The believed benefit for Cable Supplier is twofold: Using RM for project reporting would improve its precision and benefit the further implementation of RMS. Unfortunately, the paper also suggests that the requirements in Cable Supplier tend to fall under the pitfalls of poor requirement, defined by Sols (2016), as cited by Hårstadsveen (2021): Fuzzy or ill-defined requirements, unnecessary requirements, and infeasible requirements. Although identifying a low quality of the requirements, the research only provides a template for a requirement structure, excluding guidance on defining the high-quality requirements. Before a project could use requirements as the basis for progress reporting, they must be well-defined.

IEEE 1233 (1998) defines a well-formed requirement as "a statement of system functionality (or capability) that can be validated and traced, that must be met or possessed by a system to solve a customer's problem or to achieve a customer objective, and that is qualified by measurable conditions and bounded by constraints". Per this definition, the requirements have three parts: capabilities, conditions, and constraints. The requirements capability describes what the system should do, independent of the solution. The standards define the constraints as limitations set in stone, such as size limitations, laws, available time and budget, operating system, or interfaces to existing systems. The constraints are applied to all relevant capabilities, either one-to-one or one-to-many. Similarly, the conditions are measurable qualitative or quantitative attributes and characteristics stipulated for a capability to be validated and verified (IEEE 1998). Additionally, the requirements must all be unique and do not overlap, and every requirement shall be included, with their boundaries, scope, and context (IEEE 1998). To consistently capture requirements to the abovementioned standard, Cable Supplier need a structured approach.

The Institute of Electrical and Electronics Engineers (IEEE) encourages the use of a System Requirements Specification (SyRS) when the system includes both hardware and software (Pohl 1996). This live document is a set of requirements that, when realised, satisfies the expressed stakeholder need concerning the environment, usage profile, performance parameters, quality, and effectiveness (IEEE 1998). The form of these system requirements is a document, much like the SDB template developed by Hårstadsveen (2021). The standard produced by IEEE for developing this set of requirements, IEEE 1233 (1998), defines a development process as illustrated in Figure 4 (IEEE 1998). Applied to Cable Supplier, the customer provides their objectives, needs, and problems through specifications. These are often ambiguous and unclear, needing clarification and confirmation or changes based on input from those partaking throughout the lifecycle (technical community). As the customer's requirements are analysed, one must always consider the environment and how it may influence or enforce constraints.

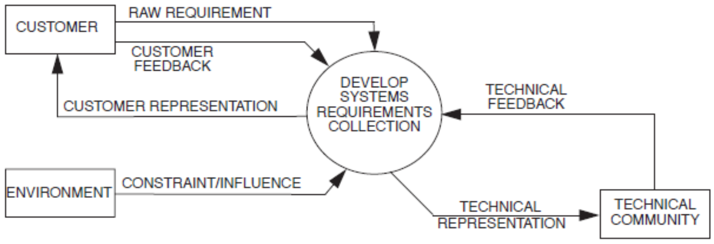


Figure 4. Developing a SyRS

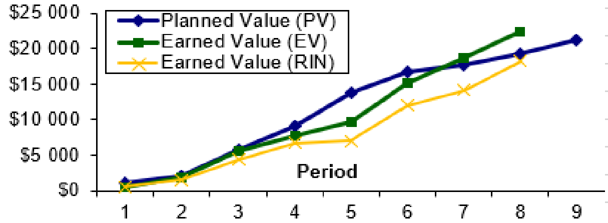
Thus, to conclude on Phase C: Cable Supplier would benefit from further development and implementation of its RMS, especially as its yet to implement the system developed by Hårstadsveen (2021), which was proven effective. If Cable Supplier were also to consider the abovementioned guidelines when defining their requirements, it would have the potential to become a crucial tool in combination with EVM and RM.

Combining Earned Value Management and Requirements Management into a tool for project reporting

IEEE 1220 (2005) states that cost, schedule, and performance measurements should be integrated to provide corrective action to any variances; supporting the implementation of requirements into progress reporting. However, combining RM with EVM is yet to be described, as it depends on the company's infrastructure and the product. Different methodologies will be proposed before choosing one in collaboration with Cable Supplier. All the tables and graphs in this section were created for this research. For the remaining paper, the achievement of requirements is defined as verifying the requirement through approved documentation, testing, or both.

Option 1 - Requirements Index Number

An exciting take on quality, based on requirements, is proposed by Miguel et al. (2019). They propose a set of performance metrics related to the quality requirements set for project execution rather than the product. It is assumed that the project execution goes through milestones structured around the quality requirements. As the milestone is reached, each requirement is graded as Pass or Not passed and given a numerical value: 1 for pass and 0 for not pass. The average of these numerical values gives the project a "Quality Index Number" (QIN). This index number indicates how well the tasks are performed the first time (Miguel, Madria & Polancos 2019). Then, this number is multiplied with the EV of a completed milestone to find the actual portion achieved. Quality Earned Value (QEV) = *EV of complete milestone * QIN*. This concept, calculating a Quality index number, renamed Requirements Index Number (RIN) for the remaining paper, is attractive due to its simplicity and intuitiveness. This method is in-line with the suggestion by Solomon (2008) for a technical measurement: a quantitative measure of requirements, including the verified percentage. Cable Supplier could use this in a format where each requirement is numerically valued (1-10) for importance and continuously traced for the project's duration. The RIN would equal the *Requirement value achieved / planned achievement of requirement value*, and $EV_{(RIN)}$ would equal *RIN * EV*. This value is similar to the abovementioned QEV but based on the number (and value) of requirements one is scheduled to have satisfied compared to actually satisfied requirements. Figure 5 illustrates the application of RIN and $EV_{(RIN)}$ to EVM in a project where the EV exceeds the Planned Value in period 7. However, the $EV_{(RIN)}$ indicates that the actual EV is smaller as the project has failed to satisfy the requirements as planned.



EVM	Cumulative Planned Value (PV)	1000	2000	5700	9200	13900	16700	17700	18700
	Cumulative Earned Value (EV)	525	1900	5500	7820	9725	15170	18770	22370
Completion of requirements	Requirement value achieved to date	3	12	20	44	50	60	62	75
	Planned requirement value	3	15	25	51	69	76	82	92
	Requirement Index Number	1,0	0,8	0,8	0,9	0,7	0,8	0,8	0,8
	Earned Value (RIN)	**525**	**1520**	**4400**	**6747**	**7047**	**11976**	**14192**	**18236**

Figure 5. RIN and $EV_{(RIN)}$

Option 2 - Performance-Based Earned Value

Another angle for combining requirements with EVM is to retract value from the EV as requirements are left unfulfiled. This principle is central in Performance-Based Earned Value (PBEV), developed by Solomon (2005, 2006, 2008), where the EV is quantitatively linked with progress and requirements. PBEV is designed to be compatible with a document-centric project execution model, such as the one employed by Cable Supplier. Through the documents, Cable Supplier proves development, maturity, implementation, and testing, which are the base measures that should be reported in EVM (Solomon 2006). All documents are designed to communicate the chosen solution and the fulfilment of applicable requirements. However, documents are often issued before every requirement is fulfiled without affecting the reported EV. The abovementioned EV(RIN) accounts for this through an index value, so PBEV proposes a framework where each requirement is given a negative EV when not fulfiled. This value represents the difficulty of ensuring fulfilment.

	Requirement (Earned Value)	**[$]**	**Type of document (Budget value)**	**[$]**	**Scheduled fulfilment**
1	Design Life must be >30 years.	9000	Dynamic analysis.	15000	Month 3
2	Maximum umbilical diameter is 200mm.	2000	Cross section drawing.	20000	Month 1
3	System Operating Voltage (U/U_0) shall be 230/127.	3500	MV technical description.	13000	Month 2
4	Maximum weight of subsea assembly is 20Te.	3000	SUTA GA Drawing.	17000	Month 4

	Month 1	Month 2	Month 3	Month 4
Actual Cost (AC)	15000	17000	12500	14000
Accumulated AC	*15000*	*32000*	*44500*	*58500*
Earned Value (EV)	*20000*	*13000*	*15000*	*17000*
Accumulated EV	20000	33000	48000	65000
Negative REV		*3500*	*9000*	
Positive REV				*12500*
Net Acc. EV	**20000**	**29500**	**35500**	**65000**

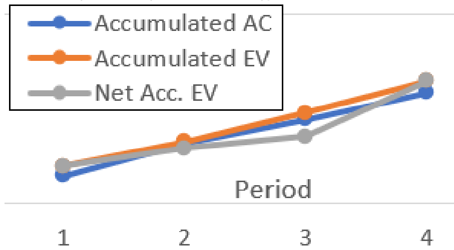


Figure 6. PBEV illustrated

Figure 6 illustrates an example where Cable Supplier delivers all documents according to schedule but fails to include requirements 1 and 3 in the first revisions of the applicable documents. However, both requirements are included in the second revision of the documents, sent in month 4. The graph in Figure 6 indicates that traditional EVM would show a project ahead of schedule through the four first months; due to deliveries according to schedule and fewer hours used than budgeted. However, due to a few unfulfiled requirements, the PBEV shows a project behind schedule in months two and three before catching up in month four.

Option 3 – Performance-Based Earned Value requirement status

In addition to the above method, Solomon (2006) proposes another form of PBEV, based purely on requirement traceability and its verification. Whereas the earlier options have traced whether the requirements are fulfiled or not, this option (3) relies on recording the status of all requirements (Solomon 2006): defining the requirement, validating the requirement, determining the verification method, allocating the requirement, document verification procedure, and verify that the requirement has been met. These activities shall be weighted by rules of credit and included in the baseline schedule; the way documents are currently managed. The figure below shows the planned and actual completion of activities for a work package and the EV graph after weighing the activities.

	Umbilical Cable Design	1	2	3	4	5
Planned	Define	13	8			
	Validate	9	9	3		
	Validate Methods	2	17	2		
	Allocate	1	9	11		
	Verify Document		9	10	2	
	Verify Requirement			4	6	11
	Accumulated PV (Weighted)	**86**	**206**	**284**	**344**	**450**

	Umbilical Cable Design	1	2	3	4	5
Actual	Define	9	10	2		
	Validate	4	12	4	1	
	Verify Methods	2	11	5	3	
	Allocate	2	14	3	2	
	Verify Document		12	8	1	
	Verify Requirement			6	15	
	Accumulated EV (Weighted)	**53**	**188**	**291**	**450**	**450**

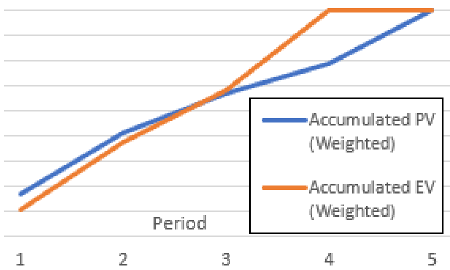


Figure 7. Option 3 illustrated

These graphs can be produced for work packages or the entire project. The nature of the requirements makes them easier to use for reporting on specific components, sub-systems, or processes. Where documents rely on input from several sources, it is easier to define the requirements as single sources: they are more independent than documents. For example, the current EVM infrastructure cannot produce a graph for the umbilical cable alone. The documents used to define the design and specifications of the umbilical are few: umbilical cross-section drawing and the cross-sectional analysis. This analysis depends on other factors, such as the design of end-terminations and input on the operating environment. The nature of the requirements makes them easier to use for reporting on specific components, sub-systems, or processes. As a result, the document must wait for input from one or all sources, making the reporting inaccurate. On the other hand, the number of requirements tied to the umbilical cable will always exceed the number of documents, and they are less prone to be put on hold waiting for input.

The last variation of PBEV considered is the application of Technical Performance Measures (TPMs), which are defined and evaluated to assess how well as system is achieving its performance requirements (Solomon 2006). This concept is rooted in SE, as Roedler et al. (2005) used technical measurements to assess how well the technical solution complies with defined performance. Roedler et al. (2005) highlight a clear relationship between TPM, Measures of Effectiveness (MOEs), and Measures of Performance (MOPs). MOEs shall provide insight into the system performance of the proposed system, seen from the client's POV, independent of the technical solution. It is the metrics by which an acquirer will measure satisfaction with products produced by the technical effort (IEEE 2005). The MOPs are closely related, defined by IEEE 1220 (2005) as an engineering performance measure that provides design requirements necessary to satisfy a MOE. They are often quantifiable and used to provide a progressive assessment of the technical progress and conformance to requirements (IEEE 2005). TPMs are derived from or provide insight into the MOPs so that the project can assess the compliance with technical requirements or goals (Roedler, Martin & Jones 2005) and provide an early indication of technical problems (Defence Acquisition University Press 2001). In order to do this, TPMs estimate the value of key performance parameters of the design through engineering analyses and tests (Roedler, Martin & Jones 2005). Typical TPMs are often centred around system performance requirements like range, weight, timing, accuracy, and size (Roedler, Martin & Jones 2005). Unfortunately, it is challenging to define such characteristics for Cable Supplier, as the component design phases are short, and the requirements are either fulfilled or not: Can provide required power – yes or no, SUTA weighs less than 20Te – yes or no. The cable must be 15346m long – yes or no. Although TPMs have great potential, it is not thought that the RMS, or knowledge of RM, is at the required level in Cable Supplier.

Option 4 – Requirement Attributes Method (RAM)

Lastly, this research proposes a combination of EVM and RM by looking at requirements attributes (RA). INCOSE (2015) defines an attribute of a system as "an observable characteristic or property of the system". Likewise, ISO/IEC (2019) defines a requirement attribute as an "inherent property or characteristic of an entity that can be distinguished quantitatively or qualitatively by human or automated means". As abovementioned, this definition aligns with IEEE 1233 (1998), stating that measurable conditions are fundamental in well-defined requirements.

ISO 29148 (2018) states that descriptive attributes should be defined to support the analysis and management of the requirements. Another paper (Wheatcraft, Ryan & Dick 2016) states that defining attributes may be used to provide metrics to show the status of the requirement development. The following list is requirements attributes compiled and cited by Wheatcraft et al. (2016). Only the attributes that may be relevant for the research are included: Priority, status, cost, difficulty, revision, verification, and validation (Young 2004). Identification, stakeholder priority, difficulty, and design constraint (ISO/IEC/IEEE 2018). Status of documentation, implementation status, and criticality (Pohl & Rupp 2010). Risk level, actual cost, and estimated cost (Hull, Jackson & Dick 2011). Requirement verification status and key driving requirement (INCOSE 2015). Defining all of these attributes for the requirements of Cable Supplier would allow management to generate reports for specific aspects of the project on demand. However, one should be selective when defining a project's attributes (Wheatcraft, Ryan & Dick 2016). It takes both time and effort to maintain them (Wiegers 2005), and Cable Supplier lacks the infrastructure and experience needed. As a result, the following four attributes are included in further research:

- Status of Requirement: Draft, in development, ready for review, in review, approved. This attribute indicates how well defined and understood the scope is. Rules of credit applies.
- Priority: How essential is the requirement to the stakeholder but does not have to be the most critical in terms of functionality, measured on a scale of 1-10.
- Criticality: describe requirements that are critical for the system to function, measured on a scale of 1-10. Once all such requirements are fulfilled, one is left with a functioning system.
- Key Driving Requirement (KDR): Any requirement that will significantly impact cost or schedule if failed to be achieved, measured on a scale of 1-10. Once completed, the cost- and schedule related risks in the project will decrease.

Each of these must be assigned with values during the early project stages. When completed, they will be reported over the values from EVM, as illustrated through an example in Figure 8.

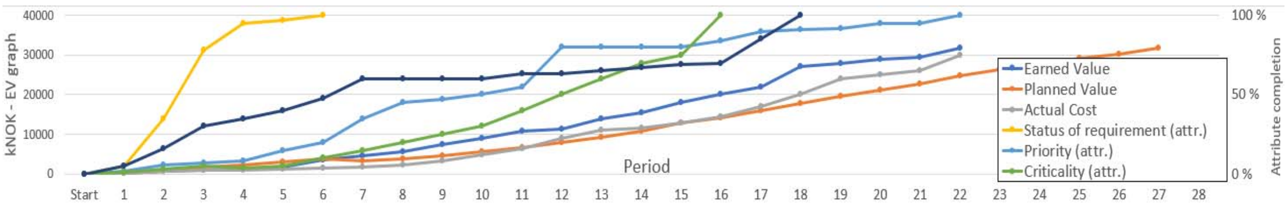


Figure 8. Requirement attributes illustrated (value in NOK – Norwegian Krone)

Selection of solution to implement at Cable Supplier

In order to wrap up Phase D, a workgroup was assembled to select the most appropriate solution amongst the four possibilities mentioned above - all defined by the researcher. The researcher led the workgroup, which used a Pugh matrix as its primary tool. Pugh matrices aid the thinking process about problem statement and solution suitability (Muller 2012) and further explore alternative methodologies (Muller et al. 2011). The participants included two project engineers, the researcher behind the paper on RM in Cable Supplier and the researcher of this paper, with a combined 29 years of experience with project engineering and umbilical production. During selection, the RM system proposed by Hårstadsveen (2021) was assumed to be integrated as planned. *Ease of implementation* and *maintenance* represent the implementation process and would not be weighted highly if weighting was applied. However, they are included as one has seen a resistance to change, signalling that the future benefit must be substantial for it to be implemented. As seen in Figure 9, although requiring improved infrastructure and more resources to be maintained, RAM is deemed best suited for future implementation, by a small margin. Option Null represent the current methodology.

Criteria	Option Null	Option 1 - RIN	Option 2 - PBEV	Option 3 - req. progress	Option 4 - Attributes
Ease of implementation	5	3	3	2	2
Resourses required to maintain	4	3	3	2	2
Intuitiveness	4	4	4	3	3
Accuracy and trustworthiness	1	3	2	4	5
Ability to provide full picture	1	2	2	4	5
	15	**15**	**14**	**15**	**17**

Figure 9. Pugh matrix used during the selection process

Verification of selected methodology

In order to provide a proof of concept that the method of attributes is feasible; this research produced a graph based on a real-life completed project. To do so, the research generated an excel file for assigning value to attributes, spreading it across the timeline, and generating the graph that can be seen in Figure 10. The below set of graphs proves that the method is feasible. The ten most essential requirements of the projects were identified based on the top-ten requirement prioritisation technique (Bühne & Herrmann 2019; Berander & Andrews 2005). However, this research could not define all the historical requirements, their attributes, and their date of achievement. As a result, the remaining requirements account for 50% of the collective attribute value and are added linearly.

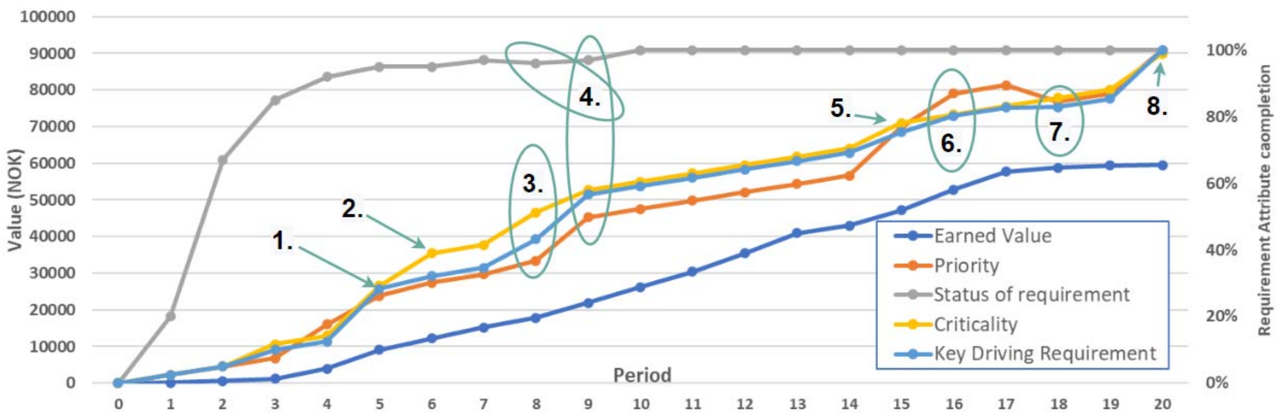


Figure 10. Requirements attribute method applied to a real-life project

Some of the main events are marked to illustrate how the graphs can explain events qualitatively compared to the EVM graph. The events are as follows:

1. Cross-section analysis approved: verifying all requirements related to the cross-sectional design.
2. All analyses related to design life approved – verifying that the system is fit for 20 years.
3. Difficulties with sea bottom stability were resolved by adding a vertical anchor to the scope, making the system design compliant with the initial requirement.
4. Requirement changed from installation basket to turntable, making Cable Supplier compliant.
5. Diver-less BS successfully installed – making Cable Supplier compliant with an essential requirement to the client.
6. EFAT approved.
7. EFAT disapproved due to required rework on end-terminations.
8. Verification test reports approved – marking the final tests for the system and the last requirement with a value tied to technical performance.

Analysis of Cable Supplier case study

This empirical case study aims to explore how much the application of RAM to a real-life project would improve its progress report and is thus an explanatory study (Yin 2009). This methodology allows researchers to retain a holistic and real-work perspective of the case (Yin 2014). Furthermore, a case study fits the methodology by using multiple sources of evidence such as interviews, surveys, literature search, and analysis (Runeson & Höst 2009).

The study follows the six case study stages developed by Yin (2014): Plan, design, prepare, collect, analyse, and share. Where preparation, collection and analysis were directly applied. When preparing for the case study, specific primary attributes were considered: asking good questions, being a good listener, staying adaptive, having a firm grasp of the issue, and avoiding bias (Yin 2014). Furthermore, permission from management to conduct surveys and interviews was granted. In the following stage, data collection, the researcher decided on several sources – to ensure construct validity (Yin 2014): documentation, interviews, physical artefacts, and interviews. Documentation is the historical progress reports and the results from the literature review performed as Phase C. The physical artefacts would be the excel files used by Cable Supplier to produce the EVM graphs and the result of the SDB pilot project. As part of Phase D, a survey was combined with interviews to ensure data triangulation: a survey using the Likert scale – a common tool for measuring attitude (Jamieson 2004) and the interview consisted of a set of open questions.. There was no overlap between the participants of the two forms of interviews. Lastly, the chain of evidence (Yin 2014) is upheld by including all interview reports in appendices 5 and 6. The below subsections are the result of the fifth stage.

Case study results

The survey aimed to assess whether RAM is perceived as an improvement for precision (accuracy) and coverage (overall "health") by its internal stakeholders. All respondents agreed that RAM is more accurate than the ES curve alone, and 71% agreed that RAM provides a more complete understanding of the project status. Overall, the survey provides results favouring RAM, both over the current tool and as a good tool for reporting progress.

The questionnaire aimed to assess the suitability of RAM within Cable Supplier's infrastructure and project execution. Five employees of Cable Supplier participated: a project manager, a team leader, two project engineers, and the Project Lifecycle Management system owner. The interviews were conducted separately except for one occasion, all initiated with a description of RAM. After being presented with its fundamentals, all participants understood the trend analysis involved. This result indicates that the graphs are more intuitive than thought during the selection process, solidifying RAM as the preferred choice.

Comparing RAM and the current tool. All participants concluded that RAM did a better job than the current EVM tool (referred to as s-curve in the responses) in providing an accurate and complete picture of the project status. Several shortcomings of the current graphs are listed as reasoning, such as how the EVM graphs fail to report on challenges, incidents, and (closure of) risks. The team leader and the project manager agreed that RAM provides a fuller and less ambiguous picture and would be instrumental in project reviews. The PM also stated that it is always preferable with more information, especially illustrative as in RAM. Although the EV graph is illustrative, it is rarely the actual focus on historical progress reports. An analysis of historical reports shows that they rely on written descriptions of progress, with no reference to the EV graphs attached. The same applies to the excel files used to generate the EV graphs, which are clustered and non-intuitive, indicating a reluctance to improve, likely based on a view that it is "not part of the future". These observations further indicate that the current tool lacks credibility and thus needs improving.

Suitability of RAM to Cable Supplier. The respondents stated that RAM aid a better interpretation of the EVM graphs. Primarily, it is pointed out, would it explain periods where the document-based EV graph indicates little or no progress, such as the early engineering phases. The PM stressed that the lack of progress in the early phase is expected, as evident in the modest incline on the EV graph seen in Figure 10. Fortunately, Cable Supplier management is aware that engineers need to understand the scope of work before producing any documents. Early scope definition is a stated goal in the early phases of projects within Cable Supplier. Introducing a measure of scope definition would therefore be welcomed, not only as a measurement but indirectly as a means to emphasise this process. Additionally, it was mentioned (verbally) that engineers are often tempted to partially understand the scope of work before starting work on the documents, as one is often pressed on time. The introduction of RAM cannot directly increase the time available in this phase. Still, in theory, it will save time throughout the project, freeing up time for requirement definition in the next project.

In addition to its primary purpose of project reporting, it was proposed that RAM might be beneficial in other aspects. Over-engineering is a common problem caused by a lack of defined requirements and a need to play it safe. As requirements are better defined, one might find that the hours used for engineering activities and analyses decline due to more accurate analyses and fewer document revisions. Furthermore, one could use the tool to assess how many requirements different products satisfy and use this to create standardised products, which is a process Cable Supplier already initiated.

Moreover, it was noted by the PLM system responsible that it would be better to display the completion of requirements as a whole number rather than by the percentage of requirements completed. The belief was that it would be better to do it as a value in the same manner as traditional EVM, based on the date met and planned. However, as discussions concluded that the additional work required to tie all requirements to a date and value is substantial, the use of percentage was deemed best suited at this stage. Lastly, it was also noted that RAM's foundation would allow Cable Supplier to effortlessly generate EV graphs based on requirements rather than a document, as proposed in Option 3. However, it was thought that this aspect would remain a potential future change to maintain something familiar within RAM for the clarity of potential implementation and the case study.

Barriers to implementations. The researcher expected the respondents to consider the extra time needed in the early stages of the projects to define requirements and assign attributes as a drawback to RAM. However, it was a broad consensus that this should be performed regardless, to an even more significant extent than today or planned through the SDB. The project engineers suggested that RAM would double as a tool for ensuring all requirements are met, as an RMS should. However, it was highlighted that it must be an organisational tool used by everybody and combined with the more extensive PLM system to be practical. Performing this implementation is considered a significant barrier to the acceptance of RAM, along with a lack of motivation for change in the current way of working. The PLM system owner (and RM responsible) mentioned this as a fact, as he had first-hand experienced this refusal towards change when chasing integration of the SDB. His experience was supported by looking at the SDB structure generated in a pilot project. The team failed to prioritise it, making it lean to the extent where one would resort to the old ways instead of consulting the SDB, thus making it redundant. People are naturally reluctant to change, and as pointed out by the team leader, especially towards changes that could make the work more rigid if not performed appropriately. Unfortunately, it is also made difficult by the nature of current projects. Most are considered fast-track, and most PMs would rightly be reluctant to act as a pilot project.

To conclude on the motivational problem, it is apparent that all respondents would welcome a more extensive extent of RM within Cable Supplier. However, their co-workers need help understanding its potential benefits. The PLM system owner was visibly enthusiastic, as when consulted throughout the research, he considered the RAM an extension of the RM vision within Cable Supplier. Therefore, Cable Supplier should increase the understanding of RM amongst its users, as RAM would impose what could seem like an overwhelming number of requirements. Another drawback mentioned was that the tool generates information that one might want to withhold from the client. This point especially applies to the attribute of priority, which could be read as a measure of how satisfied the client is or should be. In general, Cable Supplier management must assess the suitability of each attribute's graph for external distribution.

Conclusion

The primary shortcomings of EVM applied in Cable Supplier is imprecision and failure to provide a complete picture of the project. It is inaccurate, as the input is based purely on the progress of external documents, neglecting the number of review cycles and all internal processes and documents. It does not provide a complete picture, as it fails to assess the technical performance, why the project is late or early, or the amount of risk remaining. As a result, this research proposes a combination of RM and EVM, producing graphs based on the completion of requirements and their weighted attributes. This output will give a basis for explaining and expanding on the progress shown in the EV graph.

As a first step in assessing its suitability, RAM was chosen as the preferred solution in Phase D. Then, the methodology was favourably received by Cable Supplier through two separate forms of interviews: the survey confirmed that RAM improves precision and degree of coverage, and the questionnaire supports its fit within Cable Supplier’s vision and way of working. However, it was highlighted that there are significant barriers to implementation - specifically, the lack of motivation regarding requirements management and change in general. As a result, this research concludes that documents alone cannot provide an accurate and complete view of the project's health. However, combining RM and EVM as described in this paper offers a considerable improvement. Although RAM would be capable of reporting progress without EV graphs, the EVM output is needed in the short term for familiarity and credibility.

Management must assess whether RAM can be applied to external reports in its complete form. The attributes of Priority and Key Driving Requirement may be kept internal. Status of Requirement is a two-way process and should be reported to all stakeholders involved. Lastly, Criticality would be the most valuable attribute to share with the client. However, for the client to gain value from it, they will need to be part of the weighting process or be given the different values attached to the requirements.

Due to the nature and boundaries of the research, the survey and questionnaire sample size was limited. All participants were known associates to the researcher and could give more positive feedback. Likewise, the researcher's belief that the solution is suitable might have affected the introduction of RAM ahead of the questionnaires. However, the questionnaire participants alone have 60 years of experience in positions directly affected and are believed to have provided valuable and objective output. Altogether, it is believed that the conclusion is based on an adequate foundation.

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