The Origins and History of Cost Engineering

Introduction

Cost Engineering, defined as the application of cost estimating, cost management, and engineering economics to capital asset management, has a long history. This paper will chart the evolution of cost control from its beginnings as an accounting function, through to the emergence of Cost Engineering as a distinct discipline in the first half of the 20th Century[1].

The relationship between time and money has been recognized for at least 1500 years. The oldest recorded use of the phrase *time is money* is in the book *Della Mercatura et del Mercante Perfetto*[2] published in 1573 by Bernedetto Cotrugli. This book also described in detail the concept of double entry bookkeeping which reduced accounting errors. But while bookkeeping and accounting in mercantile trade is important, the items being bought and sold are tangible, and the price known.

The challenge facing everyone involved in commissioning and delivering a project is the product to be delivered is merely a concept that will be made real at some time in the future. Therefore, the cost of creating the project's deliverables is uncertain, and the value of the deliverable when complete and handed over can only be assumed; the intended benefits may, or may not, be realized. Whilst this challenge is perennial, the expansion in the number of engineering projects built for commercial profit in the decades prior to, and during, the industrial revolution brought the need for improved cost estimating and control into focus.

This paper traces the evolution of project cost engineering from its roots, through to the early 20th century when the concept of cost engineering was formalized, and on to the present time.

Fixed Price Contracting

The concept of fixed price contracts

From at least the 1st century BCE, the Roman State outsourced the majority of its public works. New projects, and the repair and maintenance of existing infrastructure, was undertaken by private contractors. State officials were responsible for awarding contracts and then ensuring that they were fulfilled by the contractor, according to the agreed terms[3].

---

1 To see the events discussed in this paper in a comprehensive historical timeline download ***Project Management - A Historical Timeline***: https://mosaicprojects.com.au/PDF_Papers/P212_Historical_Timeline.pdf

2 *Della Mercatura et del Mercante Perfetto* (Commerce and the Perfect Merchant) 1573 Bernedetto Cotrugli. Hardcover reprints available from Amazon (in Italian) for $20: https://www.amazon.com/mercatura-mercante-perfetto-Benedetto-Hardcover/dp/B0799M1KT4

3 Walker, D. H. T. & Dart, C. J. (2011). Frontinus—a project manager from the Roman Empire era. *Project Management Journal*, 42(5), 4–16. Source: https://www.pmi.org/learning/library/ancient-practices-infrastructure-project-management-2229

An example of public contracting is provided by an inscription describing the maintenance of the Via Caecilia (one of the great highways of Roman Italy) during a period between 90 and 80 BCE. The inscription records that the *urban quaestor*[4] had engaged a number of contractors to complete sections of the project. As part of the process of ensuring public accountability, the distance and the nature of the work are specified for each contract, with a specific cost assigned. The quaestor and each of the individual contractors are named as personally responsible for the completion of their section of the works.

The process of public contracting means each of the contractors needed to be able to properly estimate the cost of the work they were tendering for, and when appointed, manage the costs of accomplishing the work effectively. Given the Roman Republic was some four centuries old at this time, and the Roman's predisposition to importing ideas from other cultures, it is quite likely this form of contacting was much older and may have been used by other civilizations.

The alternative to public contracting was direct state control of the works. For example, the Great Pyramids and other structures in Egypt seem to have been built by paid workers (some conscripted to work during quiet periods in the agricultural year). The worker's wages were paid in beer and grain, sourced from the State, and supervision was provided by appointed State representatives. In this situation, a reasonable estimate of the time and workforce need was still important, but there was less requirement for precision, the State granaries and treasury could accommodate any additional outlays.

Fast forward to the 15th and 16th centuries and most major projects appear to have been funded by the Church or State, on a needs basis. Once a decision had been made to build a Cathedral, warship, or fortification, artisans were hired and paid to accomplish the work. Smaller projects were undoubtedly still commissioned on a fixed price basis, but there appear to have been very few organizations with the resources to accept the risk of a major project.

This changed with the industrial revolution, one of the developments in this era was the emergence of large industrial and commercial organizations capable of undertaking significant projects. By the 19th century, most projects appear to have shifted back to being delivered using fixed price contracts[5]. This arrangement has continued through to modern times.

Challenges of cost estimating

Estimating the cost of any project is a difficult process; this has not changed over the centuries. When a prospective contractor over-quotes the work is likely to go to someone with a more accurate price. Underquote and there's a financial gap to fill from within your own resources.

In Roman times, failure could be career limiting at best, and was potentially fatal if the emperor's prestige was at stake. The Roman contractor needed deep pockets to bail out an underquoted project. The necessary depth of resources needed for major project (eg, the construction of the Colosseum) was achieved by the publicans (public contractors) forming partnerships and companies (*societates publicanorum*) under officials known as magisters to take on the work.

In more modern times, the consequences of under-estimating are less severe but still expensive. The creation of joint stock companies in the 16th century helped spread the pain of underquoting to the company shareholders but ultimately the underquote still has to be paid for by someone.

---

4 A public official in Ancient Rome who had charge of public revenue and expenditure.

5 For example, the construction of the Crystal Palace in London for the Great Exhibition of 1851 was contracted to Fox, Henderson and Co. for the sum of £79,800 (variations and changes increased this amount later) see: https://www.mosaicprojects.com.au/PDF_Papers/P180-Project_Governance-Building_the_Crystal_Palace.pdf

An early example of a company underquoting was the construction of the Iron Bridge over the River Severn in Shropshire, UK. The Iron Bridge is a cast iron arch bridge that opened in 1781; it was the first major bridge in the world to be made of cast iron, and was structurally successful, inspiring the widespread use of cast iron as a structural material.

Abraham Darby III, an ironmaster working at Coalbrookdale was commissioned to cast and build the bridge for a budget of £3,250 (equivalent to £410,000 today). This sum was raised by subscribers to the project. The actual cost of completing the bridge is unknown, contemporary records suggest it was as high as £6,000 (equivalent to £750,000), and Darby, who was already indebted from other ventures, agreed to cover this excess[6].

The Iron Bridge, Shropshire.

By the mid-1790s the bridge was highly profitable, the tolls were giving the shareholders an annual dividend of 8 per cent. However, it took Darby's family more than a generation to pay of his debt and reestablish the family's reputation as leading ironworkers.

The challenge of estimating remains the same today, if the estimated cost is too high you don't win the work, too low and someone ends up paying for the mistake. As discussed below, the advent of cost engineering helped improve the estimating function, but we still see regular failures such as the £4 billion cost overrun on the London Crossrail project.

Cost Accounting

Unlike estimating which is a predictive process to determine what something may cost to produce in the future, cost accounting focuses on what has occurred. It is a precise process designed to accurately record what has been spent, validate the expenditure, and to provide information to allow the correct calculation of taxation obligations, profit or loss, dividends, and to fulfil other statutory and management

6 Cossons, Neil; Trinder, Barrie Stuart (2002) [1979]. The Iron Bridge: Symbol of the Industrial Revolution. *Phillimore*. ISBN 978-1-86077-230-6.

requirements[7]. Cost accounting is closely aligned with, and a sub-set of, the organization's general accounting function. The difference being cost accounting is focused on the work, including projects, being performed by the organization.

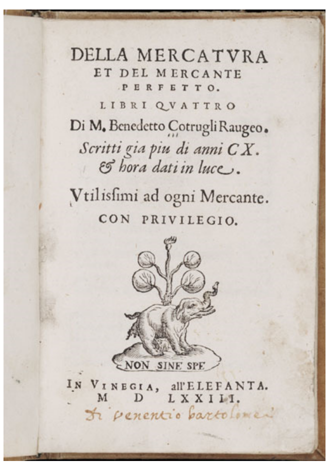
This should be more than a simple record keeping and calculation process. Cost accounting information can be used to identify trends, problems, and opportunities, during the course of a project; allowing management to identify issues that require their attention and action. Cost information is a very clear barometer of how other aspects of management such as contracting and workforce management are performing. The three primary functions performed by cost accountants in support of a project are paying for the work performed, keeping project cost records, and using the recorded information to proactively influence management actions and overall outcomes.

Double entry book keeping and accounting

The need to keep a record of accounts goes back millennia. One of the drivers for the creation of writing was the need to record financial transactions, and the development of mathematics was in part driven by the need to define land areas from both an ownership perspective and to allow the fair assessment of taxes. These developments emerged in Ancient Egypt and the Sumerian empire some 6000+ years ago. The earliest accountants worked for the rulers and the temples, compiling records in cuneiform and hieroglyphics.

Extensive trade networks run by traders and merchants grew in parallel with the civilizations. The traders would also have needed to keep account of the price they paid for their wares and the cost of transportation, to work out a viable sale price at their destination. Initially a good memory may have been sufficient, but over time the need for formal written records would have increased.

The problem with accounting system through to the 14th century, was values were only recorded once. If there was an error in entering an amount, there was no way of identifying which entry was incorrect, or even knowing there was an incorrect entry. This made finding errors, innocent or fraudulent, very difficult.



The invention of double entry bookkeeping resolved this issue. Every entry to an account ledger requires a corresponding and opposite entry to a different account ledger, and always includes at least one debit and one credit. This normally involved two ledger clerks making the entries and if done correctly, the total debits and total credits are equal (ie, balance). The trial balance at the end of each time period would highlight any discrepancies. The origins of the method are obscure and may have originated in India before spreading to Europe. But we do know that in 1340 the *Messari* (Italian: Treasurer's) accounts of the Republic of Genoa were published using the double-entry system.

The oldest known manuscript on the double-entry bookkeeping system is the manuscript for Bernedetto Cotrugli's book *Della Mercatura et del Mercante Perfetto* written in 1458, this predates Luca Pacioli's book *Summa de arithmetica* by at least 36 years. These books and their translations spread the concept of double-entry bookkeeping throughout Europe and are generally considered to be the starting point of the profession of accounting which five and a half centuries later is still going strong. The

[7] Cost accounting is defined as *a systematic set of procedures for recording and reporting measurements of the cost of manufacturing goods and performing services in the aggregate and in detail*: https://en.wikipedia.org/wiki/Cost_accounting

mechanics of double entry bookkeeping in ledgers has been largely overtaken by modern accounting software, but its legacy can still be seen in legal documents such as a company's annual balance sheet.

Paying for work

One of the challenges in projects and business generally is paying a fair price for work done. To a large extent, the doing of work is intangible, all that can be observed is the output created by the work. A manager can see a person typing at a keyboard, or using a shovel to move sand; what's difficult to determine is how efficiently the person is working. Some aspects of work can be measured, but these measures are of questionable value. For example, you can measure:

- The time taken, but you cannot measure the degree of skill and effort applied in the time,
- The outputs produced, but you cannot easily measure the quality, the difficulty, or the wastage. A skilled worker may be able to create an acceptable artifact out of substandard raw materials, saving wastage but taking longer whereas a less skilled person simply discards the material increasing wastage costs,
- The elegance of a solution; one software developer may spend several hours thinking through a problem and then write 10 lines of code that solves the challenge efficiently and elegantly, another may write 150 lines to solve the same problem.

To help minimize these problems, three basic ways of paying for work have evolved:

1. Pay for the time expended in accomplishing the work,
2. Pay for the items produced (piece rates), usually with a quality assessment before payment,
3. Use an incentive payment system that combines elements of time and production to encourage the maximum sustainable level of output and as a consequence reduce the cost per item produced[8].

For most projects a combination of approaches is needed. For example, the 1306 contract between Richard of Stow, mason, and the Dean and Chapter of Lincoln Cathedral, specified that ornate carved stones would be paid for by an hourly rate, based on the number of hours spent crafting the block, but plain walling stones would be paid for by measure (ie, piece rates). Stone mason's marks (showing who cut the stone) can found on the standard walling blocks of this cathedral.

Paying for the work done, motivating the workers, and rewarding individual skill levels, create a range of cost accounting issues. The first is the assumptions that have to be made during the estimating process about the productive capabilities and fees to be paid to get the work done at some point in the future; these assumptions set the contract price. Then the actual payments made to workers need to be verified, validated, and recorded. Finally, the current rate and cost of performing the work is a reasonable indication of future performance and this needs to be factored into any predication of project outcomes.

Subcontracting portions of the project work for a fixed price will transfer some of the challenges to a third party, but if the subcontractor has got its estimating wrong, they will happily accept windfall profits, but will be equally keen to offset losses by reducing quality, attempting to charge more, or simply abandoning the works.

[8] For more on ***incentive payments and bonuses*** see: https://mosaicprojects.com.au/Mag_Articles/SA1066_Incentivation_and_Performance.pdf

Paying a reasonable price for a reasonable amount of productive work, and knowing what these two statements represent in the real world is a challenge that sits at the heart of estimating and cost accounting.

Project cost records

Keeping accurate records of the costs expended on a project is important for a range of reasons including:

- Complying with statutory obligations
- Providing information to stakeholders and investors, and
- Providing information to assist management.

The process of record keeping is as old as the concept of accounting, the examples above are all based on contemporaneous records, and this aspect of control seems to be global. For example, the Hwaseong Fortress constructed in Korea during the years 1794 to 1796, compiled a full set of records that still exist as the Uigwe.

As the last stage of this Royal project, King Jeongjo issued orders to Che Jegong to document the Hwaseong project. His team collected all documentary records, slips, formal letters, meeting minutes, etc., of the project and started to compile the Uigwe. This work took five years and was completed in 1801, after King Jeongjo died[9].

Fast forward to the present time and the two challenges to creating effective project records are still:

1. Timeliness, records compiled years after the event do not contribute much value to the project, although they can be valuable references and serve other legal and historical purposes, and
2. The need to access specific information quickly, which requires the records to be held in a structured and accessible format[10].

[9] For an analysis of this UNESCO recognized document see the work of Young Min Park: http://www.maxwideman.com/guests/hwaseong/documentation.htm

[10] The modern concept of ***knowledge management*** provides a framework for project record keeping: https://mosaicprojects.com.au/PMKI-PBK-010.php#Process3

Organizing project cost records requires an effective breakdown structure[11]. One of the earliest diagrams of a breakdown structure I've been able to find is from a 1909 book *Construction Cost Keeping and Management*. This process of organizing, interpreting, and communicating, project cost information is the at the core of cost engineering.

Cost Engineering

Cost accounting in factories

The application of cost estimating, cost management, and engineering economics to the management of capital assets appears to be a reaction to the increasing complexity of building and managing factories starting in the 19th century, but its origins are much earlier[12].

The early developments in cost accounting appear to have occurred during the reign of Henry VII (1485-1509) when a large number of woolen manufactures moved from the cities to country villages, to avoid the restrictions of monopolistic Guilds based in the cities. These merchants established industrial communities with local crafts people being paid piece rates for the cloth they wove[13]. Each of these independent merchants had to manage their business and set prices in a competitive environment, meaning the maintenance of accurate cost records became an imperative for business success. The difference between normal accounting and cost accounting was the need to understand the unit cost of production, to allow a viable sale price to be established. This model lasted some 300 years through to the invention of industrial spinning and weaving machines and creation of factories.

The early factories and other industrial businesses were initially managed in the same way as the mines and other traditional enterprises had been in the preceding centuries. The entity was owned by a person (or family), who either directly oversaw the working of the business, or employed a manager to undertake the day-to-day supervisory and management role, under the direction of the owner. These traditional ways of managing had worked for the grand estates and the relatively straightforward industries of the 16th and 17th centuries but would quickly prove inadequate for the management of the complex enterprises created during the industrial revolution.

The first phase of industrialization was based on water power. Richard Arkwright is credited with inventing the prototype of the modern factory in 1769 to house his patented water frame spinning machines[14]. Following on from his success, water powered factories spread through the 18th century, and by the early 19th century steam was replacing water and the power source in factories[15].

11 For more on the origins of ***project breakdown structures*** see: https://mosaicprojects.com.au/PDF_Papers/P207_WBS_History.pdf and https://mosaicprojects.com.au/PMKI-ZSY-020.php#WBS

12 Historical Development of Cost Accounting S. Paul Garner *The Accounting Review* Vol. 22, No. 4 (Oct., 1947), pp. 385-389 (5 pages)

13 For more on ***piece rates*** see: https://mosaicprojects.com.au/Mag_Articles/SA1066_Incentivation_and_Performance.pdf

14 For more on ***the development of modern management*** see: https://mosaicprojects.com.au/PDF_Papers/P050_Origins_of_Modern_Management.pdf

15 Steam engines had been used to pump water from mines for most of the 18th century, but it was not until 1783 James Watt invented the 'double acting' engine that could provide consistent power to a rotating flywheel to allow steam to be used as an industrial power source.

The introduction of steam engines in the second phase of industrialization allowed the construction of ever larger industrial plants and factories in locations that suited the manufacturer. Unlike the stream-flow of a river, steam was an almost unlimited source of power that could be controlled and applied as needed, where needed.

The problem with managing large steam-powered factories is the need for systems and coordination, raw materials need to arrive in the right quantities at the right time, workers need to be trained, organized and supervised, the workflow through the factory needs to be managed, and the finished products shipped to market. By the last quarter of the 18th century, management thinkers on both sides of the Atlantic were beginning to develop theories of management focused on improving factory management. These theories became better defined and documented during the 19th century and continued to be refined through the 20th century. The key developments in management theory that lead to the emergence of cost engineering as a distinct discipline occurred in the late 19th and early 20th century.

In the period from 1870 to 1910 engineers took the lead in developing cost accounting methods:

- The modern approach to production centers and idle capacity charges were described by Alexander Hamilton Church, president of the Institute of Cost and Works Accountants, in 1900.
- Fixed-variable analysis of business costs is credited to Dionysius Lardner (1850) and was developed in France by C. Adolphe Guilbault about 1865, in Great Britain by John Manger Fells (1877) and Alfred Marshall (1890), and in Germany by Eugen Schmalenbach (1900).
- Attempts to set and use standards were made in the textile industry by G. P. Norton (1889), but developed standards date from F. W. Taylor (Shop Management, 1903), John Whitmore (1908), and Harrington Emerson (1909).

The structure of modem factory cost accounting was established before World War I, and between the wars, the factory-based cost accounting concepts were extended to most aspects of business.

Scientific management also emerged at the start of the 20th century with two of its key proponents being Frederick Taylor and Henry Gantt, and was one of the earliest attempts to apply scientific approaches to management. The main objective of scientific management was improving economic efficiency, especially labor productivity, but it also included structuring the way costs were measured and accounted.

Henry Gantt in *Work, Wages and Profits*, published 1913[16], states '*a system of management is an asset, and a good system is a valuable asset*.' In chapter 11 '*Prices and Profits*', Gantt looks in detail at the elements that affect the cost of production, their classification and how the different elements interact and affect the price of a product, and the overall profitability of a manufacturing plant. In both *Work Wages and Profits* (1913) and *Organizing for Work* (1919) he treats cost accounting as a normal business function, and it is only a small step from Gantt's approach to cost accounting, to the emergence of cost engineering as a manufacturing discipline, and then a project discipline.

Activity-based costing (ABC) is a refinement to cost accounting developed in the USA manufacturing sector during the 1970s and 1980s. ABC is based on George Staubus' *Activity Costing and Input-Output Accounting*[17]. Instead of using an assessed percentage to allocate overhead costs to production work[18], ABC seeks to objectively assign these costs. Once the cost of each support activity has been identified, the cost is attributed to each product to the extent that the product uses the activity improving accuracy and

16 Henry Gantt's books can be downloaded from https://mosaicprojects.com.au/PMKI-ZSY-025.php

17 Staubus, George J. *Activity Costing and Input-Output Accounting* (Richard D. Irwin, Inc., 1971).

18 For example, the **Hudson Formula** derived from *Hudson's Building and Engineering Contracts* (first edition 1891), simply applies the head office overheads as a percentage to mark up the cost of a claim, regardless of the actual effect of the additional work (or delay) on the operating costs of the company.

understanding. This is a precise system, but requires a relatively stable manufacturing system to be implemented cost effectively.

Cost engineering projects

The accounting processes and the management of costs on project work appear to have used the same basic approaches as those used in general business management through to the middle of the 18th century. For example, there were a number of identifiable projects undertaken before this time to construct wagonways (horse drawn railways) including the Causey Arch[19] and Causey embankment which opened in 1726 to cart coal from Tanfield to the River Tyne at Dunston, in County Durham, UK.

The construction of horse drawn wagonways started in the UK in the 15th century[20] and continued through to the introduction of the first steam locomotive in 1804[21]. The wooden rails used in the earliest wagonways were replaced by cast iron rails from 1767 paving the way for steam engines and modern railways in the next century. These early projects were directly funded by the mine owners to reduce the cost of transporting coal from the mine to the wharf. Cost control does not seem to have been a priority, the cost savings generated by wagonways were massive, and more than compensating for any construction cost overruns.

The first large-sale series of engineering projects in the UK, that serviced the new factories of the industrial revolution, were the construction of canals between the middle of the 18th century through to the early 19th century[22]. Several thousand kilometres of canal were dug in the United Kingdom between 1750 and 1830, mainly in the English Midlands. This canal boom started with the Sankey Canal near Liverpool which opened 1757, followed by the Bridgewater Canal near Manchester in 1761. From 1840 onward, the canals began to decline, due to competition from the growing railway network.

Many of these projects were financed by public subscription to the purchase of financial bonds issued by a canal company. But, the accuracy of the construction cost estimates used by the canal companies to raise their capital was to say the least mixed[23] (although many of these canals were highly profitable until supplanted by railways)[24]. A comparison of the estimate to the actual costs on a select number of canals in the table below shows an average increase in price of 279%.

---

19 Built at a cost of £12,000, the Causey Arch is thought to be the oldest railway bridge in the world, predating the invention of steam locomotives by some 70 years,

20 For more on the ***cost management of early canal and wagonway projects*** see: https://mosaicprojects.com.au/PDF_Papers/P207_Canal+Wagonway_Cost_Overruns.pdf

21 For more on the ***transition to steam power*** see: https://mosaicprojects.com.au/Mag_Articles/AA016_The_Origins_of_Standard_Gauge_Railways.pdf

22 Canals had been built in the UK since Roman times. The Roman canals were primarily for water management and irrigation, then during the Middle Ages the navigability of natural waterways was improved and extended to facilitate the use of barges to transport goods. This practice of enhancing natural waterways continued through to the 17th century. The first pure canal, constructed where it was needed was the Bridgewater Canal. See: https://mosaicprojects.com.au/PDF_Papers/P207_The_first_canal_projects.pdf

23 Sutcliffe, J., ***A Treatise on Canals and Reservoirs,*** Law and Whittaker, London, 1816: https://mosaicprojects.com.au/PDF-Gen/A_Treatise_on_Canals_and_Reservoirs.pdf

24 For more on the cost overruns on early canal projects see ***Cost Overruns on Early Canal & Railway Projects***: https://mosaicprojects.com.au/PDF_Papers/P207_Canal+Wagonway_Cost_Overruns.pdf

J. A. Sutcliffe, in his ***Treatise on Canals and Reservoirs***, published by Law and Whittaker, London, 1816[25] has this to say at page 168 *"Had the engineer told the subscribers at first what would be the fatal consequences of this canal……..; and had he given them a true statement of the expense, and a rational estimate of the probable quantity of tonnage [to be shipped on the canal], most likely the spade would never have been put into the ground; but whether giving this kind of plain, useful information, is any part of the engineer's creed, I leave the subscribers to judge by his estimates."*

Names.	Estimate.	Cost.	Royal Assent.	Capital at Cost.
	£	£		
Ballochney, . .	18,431	38,431	May, 1826	2.09
Dundee and Newtyle,	30,000	170,000	Do.	5.67
Edinburgh and Dalkeith,	70,125	133,053	Do.	1.90
Glasgow and Garnkirk,	28,479	148,195	Do.	5.12
Liverpool & Manchester,	510,000	1,465,000	Do.	2.88
Clarence, . .	100,000	500,000	May, 1828	3.00
Newcastle and Carlisle,	300,000	750,000	May, 1829	2.50
Leeds and Selby, .	210,000	340,000	May, 1830	1.62
Leicester & Swannington,	90,000	175,000	Do.	1.94
Manchester and Bolton,	204,000	650,000	Aug. 1831	3.19
Belfast and Cavehill,	7,500	38,700	Apr. 1832	5.15
London and Birmingham,	2,500,000	5,500,000	May, 1833	2.20
London and Greenwich,	400,000	733,333	Do.	1.83
Grand Junction, .	1,040,000	1,906,000	Do.	1.84
Whitby and Pickering,	80,000	135,000	Do.	1.69
Durham Junction, .	80,000	130,000	June, 1834	1.63
South-western, .	1,000,000	1,860,000	July, —	1.86
Durham and Sunderland,	102,000	256,000	Aug. —	2.51
London and Croydon,	140,000	575,000	June, 1835	4.12
Brandling Junction,	110,000	336,000	Do. 1836	3.05
			Mean,	2.79

The transition from canal mania to railway mania started in the 1820s, with even more extravagant projects being proposed and funded, and while many railways were built and some were very profitable, the cost estimating and construction cost controls were still woefully inadequate[26]. The English solution to this problem was education. In 1818, a small group of young engineers met in a London coffee shop and founded the Institution of Civil Engineers (ICE), the world's first professional engineering body. The ICE received a Royal Charter in 1828 and continues to be a major institution today. Over time the ICE set the standards for the education of engineers in the UK.

The construction of canals and then railways in the USA fared no better. But the approach to resolving the issues were based around the publication of good practice[27]. Some of the key contributions include Wellington, Gillette, and Dana.

Arthur M. Wellington published the *Methods for the Computation from Diagrams of Preliminary and Final Estimates of Railway Earthwork* in 1874, and *The Economic Theory of the Location of Railways* in 1877 (2nd. Ed. 1887). The book's first chapter on *Economic Premises* describes the principles of Cost Engineering

---

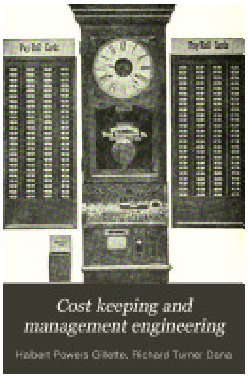
25 Download ***Treatise on Canals and Reservoirs***, by J. A. Sutcliffe: https://mosaicprojects.com.au/PDF-Gen/A_Treatise_on_Canals_and_Reservoirs.pdf

26 For more on the cost overruns on early railway projects see ***Cost Overruns on Early Canal & Railway Projects***: https://mosaicprojects.com.au/PDF_Papers/P207_Canal+Wagonway_Cost_Overruns.pdf

27 For a detailed history of the development of cost engineering in the USA see *The Early History of Cost Engineering* John K. Hollmann, 2016: AACE® International Technical Paper. Download from: https://mosaicprojects.com.au/PDF-Gen/Hollmann_History_of_Cost_Engineering.pdf

(albeit in railroading terms) requiring the *striking a just balance between topographic possibilities [design options], first cost, and future revenue and operating expenses*.

Halbert P. Gillette and Richard T. Dana published numerous unit cost data books between 1903 and 1922. Gillette saw estimating as a scientific path to better value, *where it is feasible, the engineer should formulate a unit cost equation in which all the dependent variables and constants are included, and he should then solve for a minimum unit cost*.



Gillette and Dana's 1909 book *Cost Keeping and Management Engineering: A Treatise for Engineers, Contractors and Superintendents Engaged in the Management of Engineering Construction*[28] laid out many of the practices of cost management used in construction today. Gillette saw cost accounting as the entry point to cost engineering: "*Cost keeping is but a means to an end. The means is the daily report showing what each unit of the organization has accomplished. The end is economizing of labor and materials as a result of the scientific study of the cost reports and of special timing records of performance*". Gillette dedicated his book to Fredrick Taylor, the 'father' of scientific management and clearly saw he potential for Cost Engineering (in his words 'Management Engineering'): "*The management engineer is more likely to receive a greater measure of reward for his services than the designing engineer for the results of his work are more strikingly evident to those who employ him*."

The two elements in Gillette and Dana's approach are first precisely establishing the quantity of work to be accomplished and its price, then measuring what was actually dome and its cost. A wide range of charts and cost/work breakdowns are included in the book.

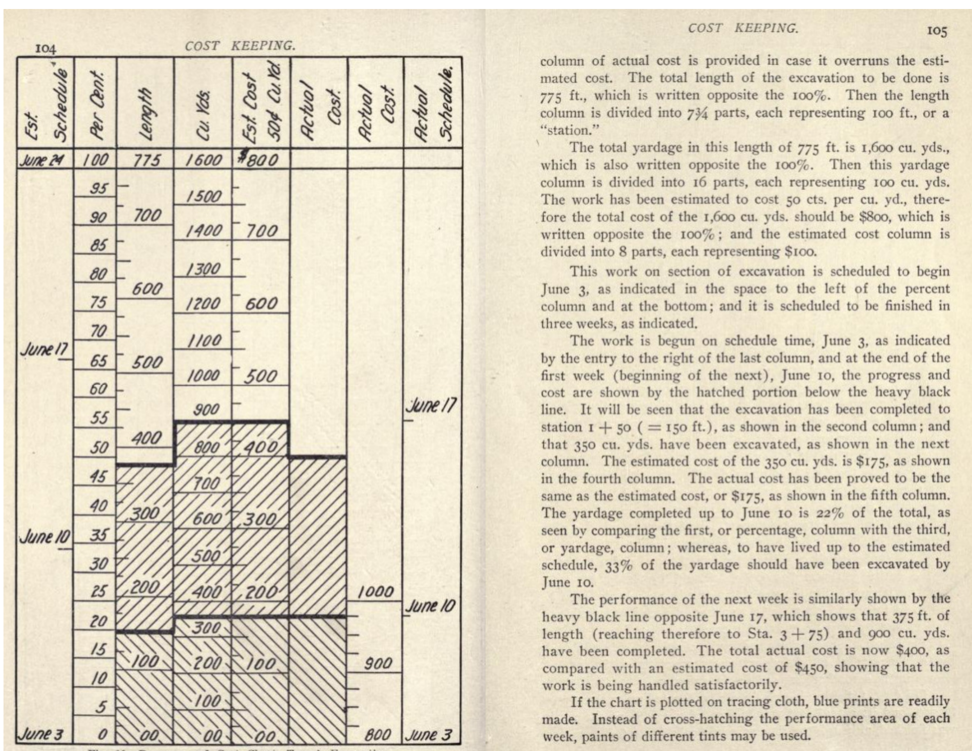


Fig. 16.—Progress and Cost Chart, Trench Excavation.

COST KEEPING. 105

column of actual cost is provided in case it overruns the estimated cost. The total length of the excavation to be done is 775 ft., which is written opposite the 100%. Then the length column is divided into 7¾ parts, each representing 100 ft., or a "station."

The total yardage in this length of 775 ft. is 1,600 cu. yds., which is also written opposite the 100%. Then this yardage column is divided into 16 parts, each representing 100 cu. yds. The work has been estimated to cost 50 cts. per cu. yd., therefore the total cost of the 1,600 cu. yds. should be $800, which is written opposite the 100%; and the estimated cost column is divided into 8 parts, each representing $100.

This work on section of excavation is scheduled to begin June 3, as indicated in the space to the left of the percent column and at the bottom; and it is scheduled to be finished in three weeks, as indicated.

The work is begun on schedule time, June 3, as indicated by the entry to the right of the last column, and at the end of the first week (beginning of the next), June 10, the progress and cost are shown by the hatched portion below the heavy black line. It will be seen that the excavation has been completed to station 1 + 50 (= 150 ft.), as shown in the second column; and that 350 cu. yds. have been excavated, as shown in the next column. The estimated cost of the 350 cu. yds. is $175, as shown in the fourth column. The actual cost has been proved to be the same as the estimated cost, or $175, as shown in the fifth column. The yardage completed up to June 10 is 22% of the total, as seen by comparing the first, or percentage, column with the third, or yardage, column; whereas, to have lived up to the estimated schedule, 33% of the yardage should have been excavated by June 10.

The performance of the next week is similarly shown by the heavy black line opposite June 17, which shows that 375 ft. of length (reaching therefore to Sta. 3 + 75) and 900 cu. yds. have been completed. The total actual cost is now $400, as compared with an estimated cost of $450, showing that the work is being handled satisfactorily.

If the chart is plotted on tracing cloth, blue prints are readily made. Instead of cross-hatching the performance area of each week, paints of different tints may be used.

[28] Download Gillette and Dana's 1909 book ***Cost Keeping and Management Engineering***: https://mosaicprojects.com.au/PDF-Gen/Cost_Keeping_and_Management_Engineering_1909.pdf

The data accumulated in the chart above is taken form detailed wage and cost records, and can then be used to assess productivity and efficiency.

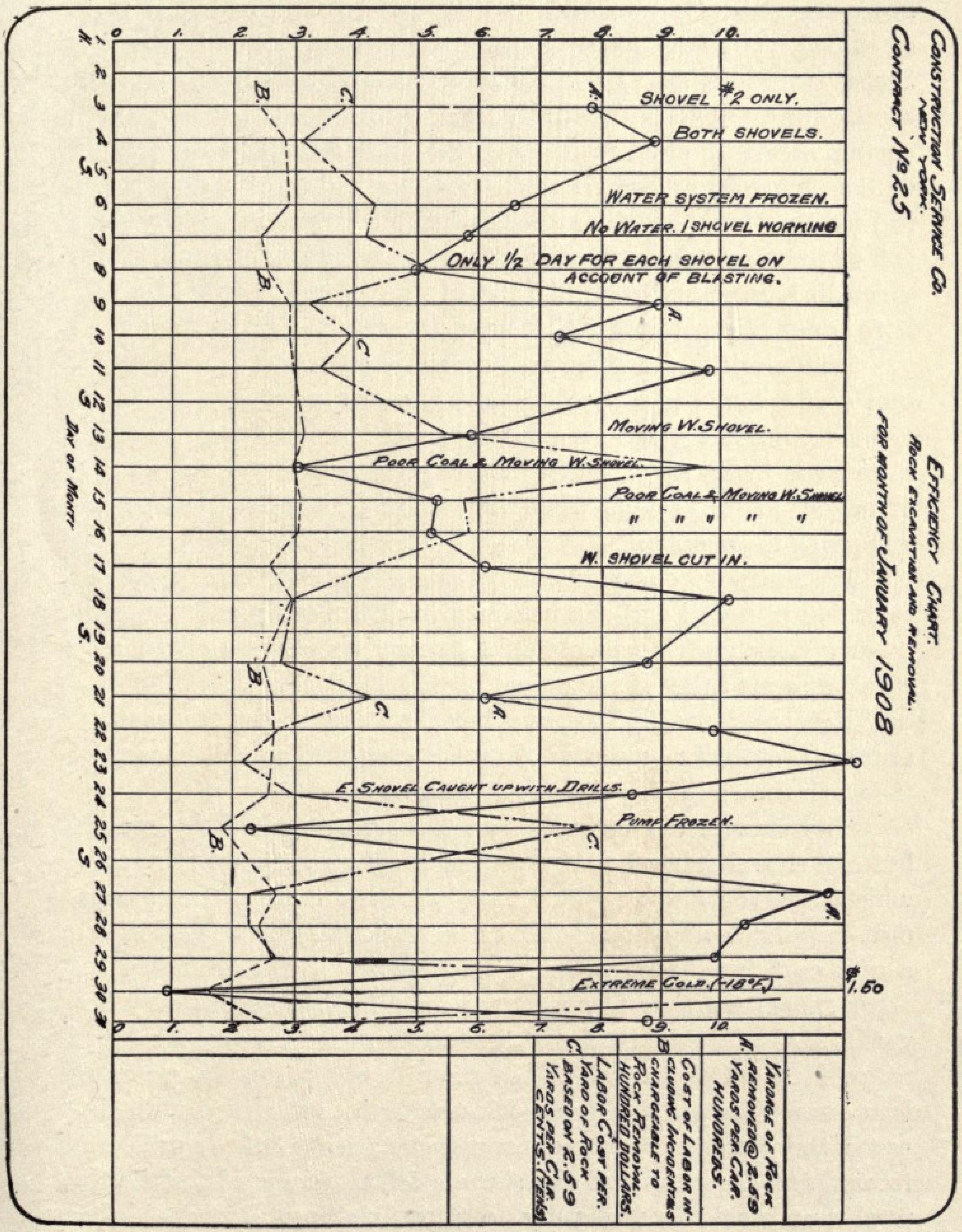


Fig. 14.—Efficiency Chart, Rock Excavation.

In the chart above, the solid line (marked A) shows the total daily yardage of rock loaded by two steam shovels, the line marked C shows the cost per cubic yard, and the line B shows the total daily operating costs. This type of chart would be updated periodically.

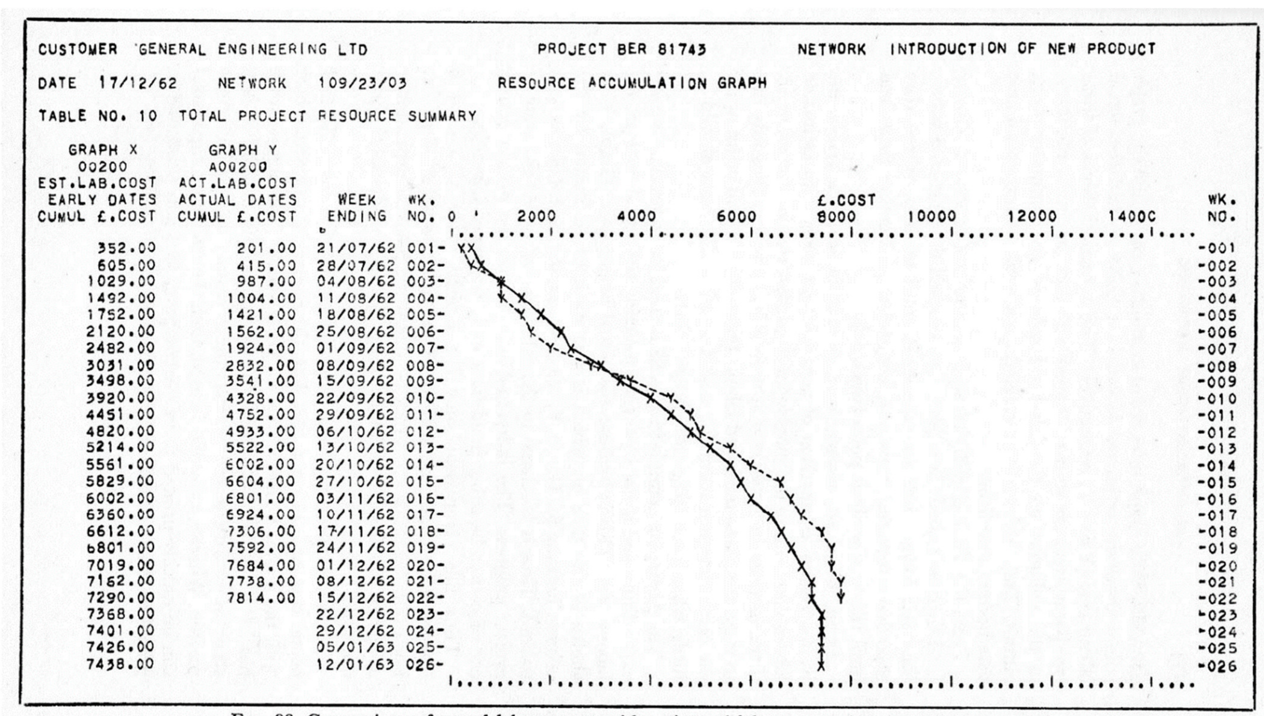
By the 1920s the USA government was in on the act! *A Manual of Planning & Progress for Construction Operations: United States War Department. Construction Division of the Army*, was published by Earle B. Morden in 1920[29]. This publication describes organization structures, cost structures, reporting requirements and much more.

Additional examples of project cost breakdowns are included in ***The Origins of WBS & Management Charts***[30] starting at page 6.

Cost engineering and cost control in both factory work and projects settled on two complementary approaches:

1. The actual costs incurred (spent) were compared with the costs planned to be spent in a period. In relatively stable, and understood, situations this gave an indication of progress achieved.
2. Scientific management expanded on this to convert *planned industry standards* (usually hours) into *earned standards* (the amount of work accomplished) and then relating them against the *actual hours* used to assess performance.

These techniques allowed engineers to begin to focus on true cost performance. However, the use of these techniques appears to have been limited to identifying areas of work requiring management attention; there is no evidence of the techniques being used to forecast future performance.



GRAPH X 00200 EST.LAB.COST EARLY DATES CUMUL £.COST	GRAPH Y A00200 ACT.LAB.COST ACTUAL DATES CUMUL £.COST	WEEK ENDING	WK. NO.
352.00	201.00	21/07/62	001
605.00	415.00	28/07/62	002
1029.00	987.00	04/08/62	003
1492.00	1004.00	11/08/62	004
1752.00	1421.00	18/08/62	005
2120.00	1562.00	25/08/62	006
2482.00	1924.00	01/09/62	007
3031.00	2832.00	08/09/62	008
3498.00	3541.00	15/09/62	009
3920.00	4328.00	22/09/62	010
4451.00	4752.00	29/09/62	011
4820.00	4933.00	06/10/62	012
5214.00	5522.00	13/10/62	013
5561.00	6002.00	20/10/62	014
5829.00	6604.00	27/10/62	015
6002.00	6801.00	03/11/62	016
6360.00	6924.00	10/11/62	017
6612.00	7306.00	17/11/62	018
6801.00	7592.00	24/11/62	019
7019.00	7684.00	01/12/62	020
7162.00	7738.00	08/12/62	021
7290.00	7814.00	15/12/62	022
7368.00		22/12/62	023
7401.00		29/12/62	024
7426.00		05/01/63	025
7438.00		12/01/63	026

FIG. 88. Comparison of actual labour costs with estimated labour costs (produced by computer).

29 Download ***A Manual of Planning & Progress for Construction Operations: United States War Department, Construction Division of the Army***, by Earle B. Morden (USA 1920): https://mosaicprojects.com.au/PDF-Gen/A_Manual_of_Planning_Progress_for_Construction.pdf

30 See ***The Origins of WBS & Management Charts***: https://mosaicprojects.com.au/PDF_Papers/P207_WBS_History.pdf

The chart above from an ICL 1300 program (1962) shows the comparison of planned vs actual costs continuing into the computer age.

The foundations of cost engineering were well established by the 1920s (at least in the USA), and the discipline continued to receive significant attention in both academia and publishing[31], with significant overlap between the various engineering disciplines. The formalization of the discipline of project cost engineering did not occur until 1956 with the founding of the Association for the Advancement of Cost Engineering. Out of all of the various project management practices, cost engineering is the only one that sees itself as an area of engineering practice. AACEi now operates globally.

Cost accounting and cost engineering has continued to develop and evolve exploiting advances in computing technology, with many organizations developing in-house solutions, some based on proprietary foundations such as SAP or Oracle, others developed from scratch. This has allowed a divergence in terminology and focus, for example Shell used VOWD (Value of work done) for many years rather than EV, or BCWP.

The functions of project cost engineering defined by the International Cost Engineering Council (ICEC) is to provide independent, objective, accurate, and reliable capital and operating cost assessments usable for investment funding and project control, and to analyze investment and development for the guidance of owners, financiers and contractors[32]. This definition suggests cost engineering covers a much wider scope than simply providing a project estimating and controls function[33], although the project cost control aspect of the discipline is still important.

During the 1940s and 50s, the concepts of cost engineering and cost accounting were used to develop two related, but independent, concepts. The first was value engineering which formalized Gillette's ideas that estimating is a proactive process focused on achieving value. The second was earned value management which integrated cost management with schedule management and scope management to create a holistic project management structure.

Cost engineering derivatives

Value Engineering

The concept of value engineering (VE) started in the 1940s at General Electric Co.in the USA. The company was experiencing a shortage of raw materials, component parts, and skilled labor due to the demands on the economy caused by the Second World War. The engineers at General Electric had to find alternative components and raw materials to ensure continuity of the production process.

GE engineers, including: Lawrence Miles, Harry Erlicher, and Jerry Leftow, began to actively seek acceptable substitutes for scarce materials and parts, that would reduce the production costs without compromising the functionality of the products. Over a relatively short period, this turned into a systematic process that not only reduced the cost of production but also provided better final products or better performance. The engineers named the technique *value analysis*.

---

31 Some of the important people involved in these developments were: H.G. Thuesen, E. Paul DeGarmo and Arthur Lesser, Jr. For details see: *ENGINEERING ECONOMY - A Historical Perspective*. Gerald J. Thuesen, William G. Sullivan - https://mosaicprojects.com.au/PDF_Papers/P207_Cost_History-engineering-economy.pdf

32 The definitions of Cost Engineering and Quantity Surveying are very similar.

33 For a list of the full scope of cost engineering see: http://www.icoste.org/whatare.htm

The value in VE is defined as the ratio of functionality to cost. Consequently, value can be improved by either improving the function or reducing the cost, or a combination of both. While functionality may be viewed in many ways including profitability, marketability, and/or various performance characteristics, establishing the baseline cost, and the improved cost requires cost engineering input.

Incorporating the consequences of a value engineering exercise into a project's costs is also directly linked to cost engineering. The estimates need revising and the chart of accounts updating to represent the project as it is now planned to occur, so as to provide a firm foundation for on-going cost management.

Earned Value Management

Earned value management (EVM) is a structured method used to provide a performance measurement system for the review of past, and the forecasting of future, performance of a project. It includes the management of scope, time, and cost, in an integrated framework based on the WBS[34], to provide the framework for both an effective project management system and a governance system. The key difference between cost engineering developed in the 1920s and EVM in the 1960s is the introduction of forecasting as a routine aspect of the EVM process.

The goal of an earned value management system (EVMS) is to quantify progress in a consistent way, so as to provide management with timely and accurate information on the current status, variances, trends, and forecast outcomes, of the project. It is based on the premise that each of the project deliverables has a value, and when the deliverable is completed, the value is earned by the project. The value earned can be compared, as at a point in time, to both the value planned to be achieved, and the actual costs incurred in performing that work. This information is then used to identify how the project is currently performing, and to project where the project is predicted to finish if no management actions are taken to rectify identified issues (negative variances).

EVM is a relatively recent development; the origins of EVM can be traced to the development of PERT/Cost in 1962, followed by C/SPCS in 1966, and DoDI 7000.2 in 1971[35]. These developments progressively shifted management focus from the reactive approaches that had become a standard part of project cost accounting to a proactive stance based on standardized approaches to calculating predicted outcomes.

Conclusion

This paper has traced the history of cost engineering, starting with the emergence of simple merchant trade accounts some 6000+ years ago, through the introduction of double entry bookkeeping into Europe, and the emergence of accounting as a profession in the 14th century; the concept of cost accounting emerged in England around the same time. The industrial revolution in the 18th century highlighted the weaknesses in both management systems and cost accounting (particularly estimating), these shortcomings fed into the development of scientific management and cost engineering in the 20th century.

Cost Engineering and cost management remain a central component of project management. Projects still require:

- An accurate estimate to be developed and a delivery price agreed with the project's customer or funder

---

[34] For more on ***the origins of the WBS*** see: https://mosaicprojects.com.au/PDF_Papers/P207_WBS_History.pdf

[35] For more on the ***Origins of EVM*** see: https://mosaicprojects.com.au/PDF_Papers/P207_EVM_History.pdf

- The agreed price has to be broken down into an appropriate chart of accounts for cost management purposes
- The resources needed for the project have to be acquired and paid for, with the payments recorded against the relevant line item in the chart of accounts
- Financial reporting and cost management are a routine part of managing the project
- The project cost information has to be reconciled with the organizations accounting systems.

Of necessity, the information used for financial reporting is retrospective, based on paid costs recorded in the accounts system. This has tended to make cost management a reactive process, constrained by accounting standards and legal obligations to report on costs and profits accurately, minimize errors, and eliminate malfeasance and fraud. All of which are vital to maintaining a well governed organization.

The concepts of value engineering and earned value management do not change these fundamental requirements. What both value engineering and earned value management do is take the project cost information and use it proactively to improve outcomes. Value engineering seeks to modify the planned project to increase value. Earned value management uses cost information as a metric to help identify issues early, and predict future outcomes. The underpinning requirement for both VE and EVM is a well implemented, rigorous and accurate set of cost information.

Creating a rigorous and accurate set of cost information for each has been the focus of cost engineering for at least the last 100 years, remains crucial to project success, and is predicted to be as important in 100 years' time as it is today.

First Published 8th March 2022 - Augmented and Updated