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The Early History of Cost Engineering

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Abstract—At the 50th anniversary of AACE International®, the association published a recap of its founding in 1956. However, cost estimating and engineering economics applied in capital asset management, the early core practices of Cost Engineering, have a much longer history – one that has not been well documented. This paper will review notable developments and leaders in these fields prior to 1956. The story starts with "De Re Metallica" by Agricola published 400 years before in 1556 (translated to English by engineer and future President Herbert Hoover and his wife Lou.) It goes on to discuss early leaders in cost estimating and engineering economics such as Wellington, Fish and Gillette. Those interested in history and wondering how Cost Engineering came to be may find this paper interesting. The paper also discusses the current AACE® mission and strategy in comparison to this history.

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Introduction

This history is not about the founding of AACE International® which is well covered by the AACE® 50th anniversary book published in 2006 [1]. It is about the initial formalization of the tenets of the field of Cost Engineering as well as a story of several pioneers in the field. It is a story of the evolution of the field of engineering economy (profitability) combined with the study and management of engineering and construction cost data for estimating and control. These were the three main interests of AACE at its founding ("AACE stressed…cost estimating, cost control and profitability" [1]). This tree of knowledge grew from civil engineering practice in the transportation industries in the late 19th century and the early 20th century. AACE later evolved as an off-shoot in the chemical engineering and process industry arenas in the 1940s. The paper will end with a discussion of the direction of growth of this engineering 'off-shoot'. However, the main focus is on three pre-AACE pioneers who are likely unknown to most readers but were well known in their day; Mr. Arthur Mellon Wellington, Mr. Halbert Gillette and Dr. John Charles Lounsbury Fish.

The Founding of AACE International

For context, this history will start at the end; the founding of AACE in 1956. According to the AACE 50th anniversary text [1], two professors, Dr. Irvin Lavine and Dr. O.T. Zimmerman founded Industrial Research Services, Inc. in 1942 to "assist businesses in obtaining and managing information pertinent to estimating project costs" in the process industries. The need for cost data was acute because process capex was exploding due to World War II. They went on to publish a book in 1949 entitled '*Chemical Engineering Costs'* [2] which by 1952 evolved into a regularly updated publication; the '*Chemical Engineering Costs Quarterly'*. In 1953, a supervising engineer from Monsanto, Norman Bach, suggested the idea of a professional cost organization to Zimmerman and Lavine (Mr. Bach suggested the title be the 'National Association of Cost Estimating Engineers'). This led to an association formation meeting in 1956. The founders were mainly allied with chemical engineering; so much so that a group lobbied to form as a special interest group of AIChE®. However, the majority foresaw a role beyond the chemical process industry. AACE's primary technical focus areas at its launch were cost estimating, cost control and profitability (engineering economics). As shown in Figure 1, these practice areas comprise the Total Cost Management (TCM®) Framework; the process for the application of Cost Engineering.

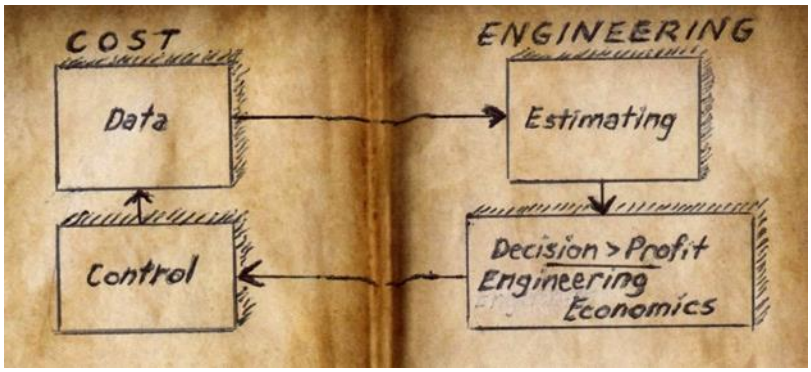

Figure 1 – The TCM Framework Process Map In a Nutshell (author)

Early on, AACE joined the prestigious Engineering Joint Council albeit without a vote. [1] This was fitting because the AACE focus areas had evolved through and were largely considered the province of the engineering profession. So it is with engineering that the history begins.

Civil Engineering, Canals and Railroads

Engineers and their achievements have been around for millennia. An early example is a treatise that discusses engineering and capital investment in mining and metals in Latin entitled 'De Re Metallica' by Agricola in 1556 (translated to English by mining engineer and future United States (US) president Herbert Hoover and his wife Lou in 1912.) [3] However, engineering was not recognized as a formal profession until the Institution of Civil Engineers (ICE®) received a Royal Charter in 1828 making it the world's first formally recognized professional engineering body. [4] The American Society of Civil Engineers and Architects (ASCE®) was founded in 1852. [5]

Figure 2 – Illustration from De Re Metallica (1556) [3][1]

[1] Copyright for Figures 2 through 6 has expired and these figures are now part of the public domain.

Civil engineering in the United Kingdom (UK) led the way primarily because of its role in the construction of canals for transport to support the industrial revolution. There was said to be a 'canal mania' that reached its peak in the UK by about 1800. [6] The mania involved investment in bond subscriptions of widely varying merit and civil engineering and their cost estimates were central to the quality of the investment proposals and decisions. The UK canal experience was considered to be both generally profitable due to good revenue and an engineering success.

However, as highlighted in this 1816 account about an English canal, engineering professionalism sometimes left much to be desired: "*Had the engineer told the subscribers as first…a true statement of expense, and a rational estimate of the probable quantity of tonnage, 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 to the subscribers to judge…What has often surprised me much more than the engineer proposing them, was, that there should be men so extremely weak and credulous, as to subscribe for the execution."* [7] That account noted that the 'engineer' behind the proposal had no experience in canal construction. Figure 3 illustrates a dismal history of UK canal cost overruns; as of 1840 it showed an average actual/estimate cost ratio of 2.79. [8]

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

Figure 3 – Canal Cost Overruns in the UK (1840) [8]

The "mania" was even less financially successful in the US where more of the canals were government funded. A contemporaneous account noted that "*It is obvious that some inherent defect must exist in American canals generally to have brought about the present deplorable results*." The financial failures were said by that author to be caused by biased estimates and unrealistic revenue forecasts; i.e., "*the cost of the works had been too great while…they labor*

under the still greater [disadvantage] *of having – practically speaking – no income.*" [term added] [9] As in England, these estimates were prepared by 'engineers' of sometimes dubious experience; however, in the US, the revenue estimates tended to be more overstated than cost.

At the time that civil engineering was formalizing as a profession in the UK in the 1820s, 'canal mania' was shifting to 'railway mania' at an even grander scale of investment. Again, ruinous public and private investment schemes were all too common and the fledging engineering field struggled to demonstrate that it could plan the work and estimate the costs with some degree of professionalism and with outcomes that investors and decision makers could rely upon. It is in the 'railway mania' era that the first of our early 'cost engineers' comes to light.

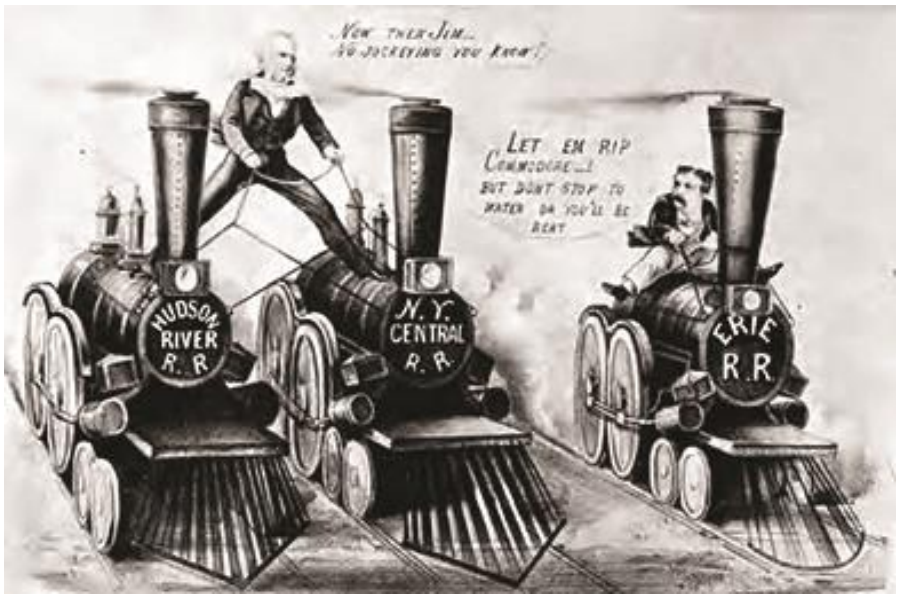

Figure 4 – "The Great Race for the Western Stakes": Railroad Mania (1870) [10]

Arthur Mellen Wellington

Arthur Wellington is sometimes considered the father of formal 'engineering economy' practice which is central to the practice of Cost Engineering and investment decision making. Mr. Wellington's ideas came out of his experiences in the US railway mania after the Civil War. He was born in Massachusetts in 1847 and was said to have been a "never-failing store of energy" as evidenced in his achievements. He graduated from the Boston Latin School and at 16 years of age began studying civil engineering as an apprentice in the office of John Henck. Mr. Wellington could not have found a better place to apprentice. Mr. Henck was a prominent civil engineer who wrote the 'Field-Book for Railroad Engineers' in 1854 and in 1865 became MIT's first civil engineering department head. Mr. Wellington's first job as a civil engineer was under Mr. Frederick Law Olmsted in the Brooklyn Parks department, but in 1868 he moved on to railway work in South Carolina as a transitman. By 1870 at 23 years of age, he was in charge of a division of the Buffalo, New York and Philadelphia railroad. [11,12]

Picking up on the scholarly tradition of Mr. Henck, Mr. Wellington became an author publishing the "*Methods for the Computation from Diagrams of Preliminary and Final Estimates of Railway Earthwork*" in 1874 at the still young age of 27. [13] From a cost estimating perspective this became a valuable reference on the practice of 'quantity takeoff'. However, estimating take-off was not his notable achievement. In 1877, Wellington published '*The Economic Theory of the Location of Railways*'. The greatly enhanced 2nd edition of 1887 became a landmark text that put engineering economy on a solid economic foundation combining engineering and cost knowledge. [14] The text was still in print as of 1910. The text's first chapter on 'Economic Premises' effectively lays out principles of Cost Engineering (albeit in railroading terms). Wellington succinctly states; "*His* [the young engineer's] *true function and excuse for being as an engineer, as distinguished from a skilled workman, begins and ends in comprehending and striking a just balance between topographic possibilities* [design options]*, first cost, and future revenue and operating expenses*." [terms added]

Another notable Wellington quotation is: "*It would be well if engineering were less generally thought of, and even defined, as the art of constructing. In a certain important sense it is rather the art of not constructing; or, to define it rudely but not inaptly, it is the art of doing that well with one dollar, which any bungler can do with two after a fashion*." Another way to say this is; an engineer who is not a 'cost' engineer supporting effective investment decision making is not really doing engineering. It is no success to build an uneconomic project on budget; success is in deciding not to build it in that manner. He was the first strong advocate of using scientific study of cost to improve economic performance.

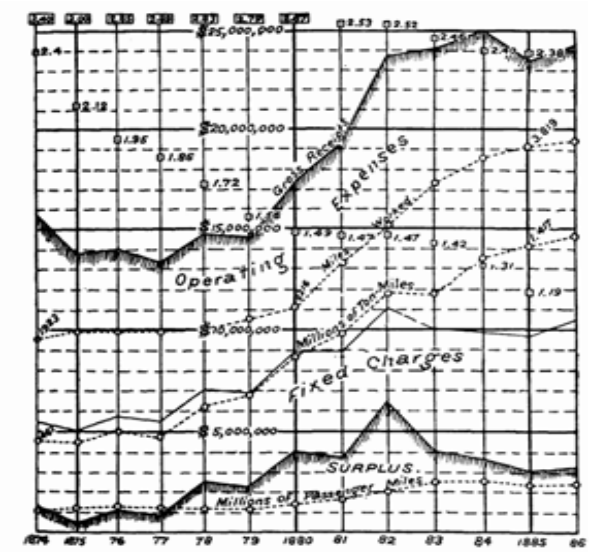

Figure 5 – Example Figure from Wellington's 'Economic Theory' (a railroad's finances) [14]

In 1887, Mr. Wellington become part owner and editor of 'Engineering News' and expanded its subscription considerably. Mr. Wellington died in 1895 at only 48 years of age working on problems of thermodynamics (having training in mechanical engineering as well). After his death, 'Engineering News' was merged with the 'Engineering Record' in 1917 by McGraw Hill to

create the magazine still with us today – 'Engineering News-Record' (ENR®). [15] Most of us (at least in North America) are familiar with the ENR 'Construction Cost Index' and 'Building Cost Index'. The topic of cost indices bring us to the next interesting personality who could be said to have picked up the ball from Mr. Wellington in respect to cost knowledge in the civil arena; Halbert P. Gillette.

Halbert Powers Gillette

Mr. Gillette was born in Iowa in 1869 and received a Mining Engineering degree from Columbia University in 1892. He worked as an assistant New York state engineer and then as a contractor in the 1890s. He became editor of the 'Engineering News' in 1903 until 1905. [16] In 1905 he founded Scranton Gillette Communications, a publishing company serving the transportation construction industry that is still owned by the Gillette family. [17]

Mr. Gillette's first notable contribution to Cost Engineering is his prodigious publication of numerous unit cost data books from 1903 to 1922 encompassing thousands of pages on rock excavation, earth excavation, clearing and grubbing, concrete, roads, mechanical and electrical (some with co-author Richard T. Dana). He stressed the importance of historical record keeping and having a strong empirical basis for estimates, and he always pointed out the value of his experience as a contractor as well as an engineer. His cost data was sometimes criticized for being inexact but his reply was that "*No book on cost data is any more fool proof than any other technical publication. It requires as much judgment to use costs intelligently as to use tables of safe stresses in engineering design. To the technical student of limited experience it should offer an introduction to the economics of engineering*."[18]

He also saw estimating not as a form of accounting but as a scientific path to better value as in his quote; "*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*." He also highlighted the importance of accuracy and the reality of risks, including today's hot topic of 'optimism bias' as in this quote: "*perhaps to the basis of the phenomenon of underestimating there is the psychological fact that most men are optimists*." In that respect he recognized the need for contingencies of "*commonly 10%, and not infrequently…a much higher percentage.*"[18]

World War I led to major price increases so Gillette republished and greatly expanded his cost data in a 1922 edition but as part of that exercise he also studied escalation. He found wages increased more or less steadily over the decades but commodity prices "*oscillated*" (more on his interest in cycles later). For that reason he dealt with hours and commodity prices separately. [19] It was likely his success with publishing cost data and the need for updates that led ENR magazine to add its 'Construction Costs' section in 1927.

His other notable contribution was to the practice of cost control. His text with Richard Dana titled 'Cost Keeping and Management Engineering' in 1909 laid out many of the practices of

cost management used in construction today. An example of his work which should be familiar to most cost engineers is in Figure 6 which breaks down the construction cost accounts. [20]

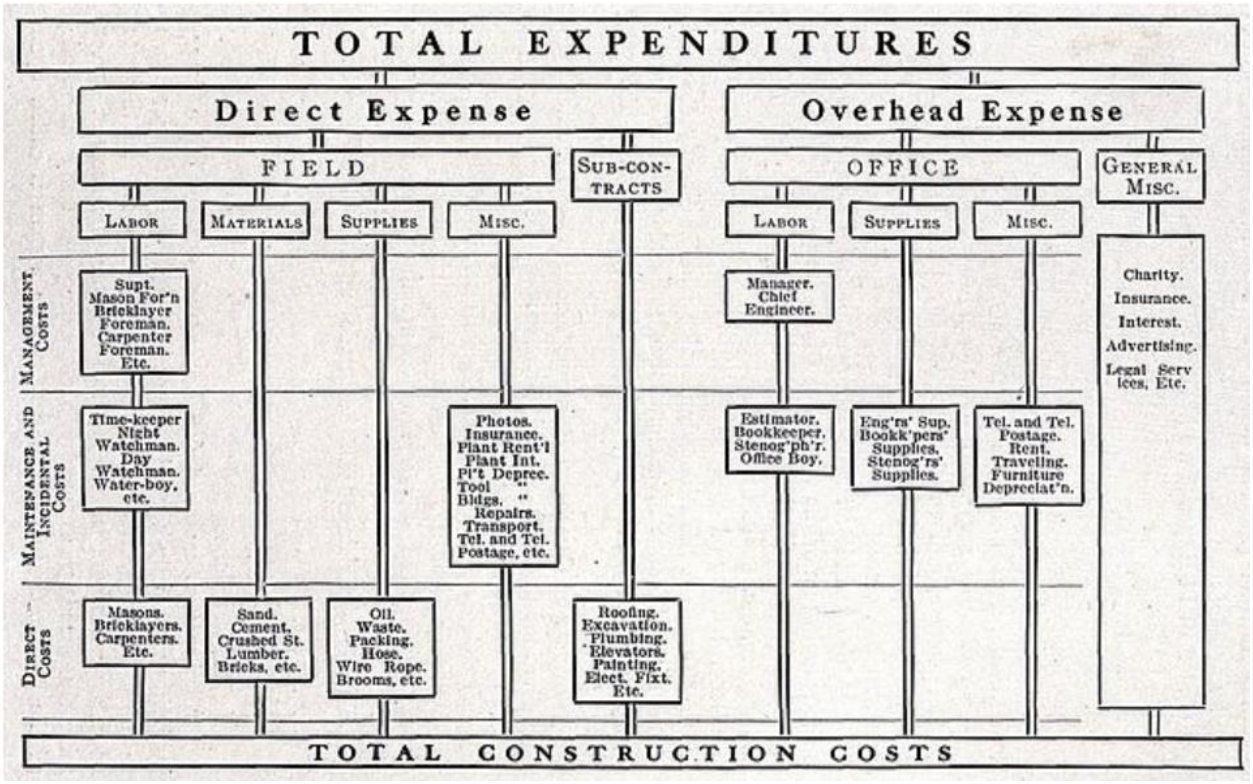

Figure 6 – Gillette's Construction Cost Breakdown (1909) [20]

Many at the time viewed cost control as little more than accounting. Instead, Mr. Gillette saw it as the entry point to engineering as summarized in this quote: "*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*" (note: he dedicated his book to Frederick Taylor who had made a name in the practice of time studies.) In that respect Gillette saw the potential value of a field of 'Management Engineering' (i.e., Cost Engineering) in this statement: "*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.*" [20] Of course, what is evident to the business is *profitablity*!

Mr. Gillette died in 1958. In his later years, his interests shifted to the study of weather cycles. His theories were seen as somewhat bizarre at the time, but as a trained mining engineer he saw evidence in the geologic record of weather cycles in lake clay deposits. He ascribed the cycles to interplay of the sun and planets in the solar system. [21] This varied interest attests both to his engineering training and statistical abilities. While Mr. Gillette built mightily on Mr. Wellington's foundation in respect to empirical cost data and cost control, the next personality (and contemporary to Mr. Gillette) built on the engineering economy foundation; his name is Dr. John C. L. Fish.

John Charles Lounsbury Fish

Dr. Fish was born in 1870 in Ohio. He graduated with a degree in Civil Engineering from Cornell University in 1892 and joined the faculty of Stanford in 1893; he taught at Stanford for the next 42 years. He taught courses in railroad engineering and other topics, but is most remembered for his work in engineering economy [22]. His text published in 1915, *'Engineering Economics; First Principles*' [23], won awards for original research from Cornell and was the leading text book on the topic for over 20 years. It established Stanford as a leader in the field of engineering economy.

In his book on Engineering Economics, Fish credits his interest in the economic side of engineering in part to Mr. Gillette. The text starts out with this simple definition of the topic: "*Economic selection is the choice based solely on the long run least cost*." From that statement he goes on to break down all the elements of cost from first costs through operations and applies the concepts of interest and the time value of money. [23] These concepts are of course central to Cost Engineering's body of knowledge.

The text also provided the engineering student with basic principles of cost estimating for first cost, operating cost and salvage costs. It includes references to many sources of cost data and on estimating methods. It also recognized different estimating methods based on different levels of scope definition including "preliminary estimates" based on gross unit costs or cost ratios, and on through "complete analysis" at a detail level. Like Mr. Gillette, he also stressed the need to have historical databases as well as pre-built conceptual estimating methods. In his words; "*records should be sorted, sifted and studied as soon as made…selected data should be tabulated, and ratios, relations and laws, which may be of direct use in making preliminary estimates should be derived from the data and recorded in the shape of formulas, or tables, or charts, all of which should be accompanied by descriptions of all pertinent circumstances and conditions of the work from which the data are drawn.*" If historical data management and empirical research are weak practices in Cost Engineering today, it is not for lack of recognition of the need.

Notable Mentions

The three gentlemen above were leaders in cost estimating, cost control and engineering economy. However, by focusing on just three, this paper doesn't mean to diminish the contributions of others. For example, both Mr. Gillette and Mr. Fish pay homage to Frederick Taylor in respect to management science. In the mechanical field, Mr. Francis Burton published a text in 1896 on the preparation of engineering estimates for engines and the like. [24] In 1907 a Mr. Harwood Frost summarized about twenty cost data sources in addition to Mr. Gillette. [25] Another notable figure includes Roger Scudder Denham, who first defined a field of practice he called 'Cost Engineering' in 1919. His texts cover what is now called 'Activity Based Costing (ABC)' in manufacturing (coincidentally, his text was titled the 'A-B-C of Cost Engineering' although he called his practice 'cost finding', not what is known today as ABC.) [26]

The list goes on. It is humbling to realize that so much of what cost engineers do today was done and documented over 100 years ago.

Cost Engineering is Part of Engineering

The foundations of Cost Engineering (estimating, cost control and engineering economics) were laid out and documented in the realm of Civil Engineering by the 1920s. Cost estimating and engineering economy were shown to be central to the engineering body of knowledge; as such there is no early history that anyone suggested a separate 'Cost Engineering' practice. Indeed, Mr. Gillette saw 'management engineering' as being of higher value than 'design engineering' but in a continuum of the engineering profession. Engineers were desirous of gaining a respected role close to the decision makers; i.e., those with power. However, in the 1920s, engineering was still trying to find respect in society. A humorous example of the challenge is a story told by engineer and later US president Herbert Hoover. He recalled having a cultured conversation with a woman when she asked what his profession was. He responded "*I am an engineer*." She reacted with shock and said "*Why, I took you for a gentleman*." [27] Considering how important being close to the decision making process was to engineering prestige, the successful founding of AACE as a separate engineering association focused on profitability is a remarkable anomaly.

AACE found its opening in the engineering arena via Chemical Engineering which did not have a textbook until 1923. [28] Indeed, the process industries had no cost data source until Zimmerman and Lavine's book in 1949. The newness of Chemical Engineering was an opportunity to carve out a separate space for Cost Engineering. However, it was no sure thing; as mentioned, a group lobbied for AACE to form as an AIChE interest group. AACE's engineering origins and ties are unique. For example, the American Society of Professional Estimators was formed the same year as AACE but laid no claim to 'engineering' status. Nor did the Project Management Institute include investment decision making in its original body of knowledge in 1969. Cost Engineering is the only profession in the project and cost management arena that defines itself as an area of engineering practice.

Cost Engineering's Future

The fact that Cost Engineering evolved as a branch of engineering raises the question of whether it is still evolving as such. In 1956, over 90% of AACE members were engineers. [29] It is no surprise that early outreach by AACE included joining the prestigious 'Engineering Joint Council'. The AACE Constitution still states that TCM is: "*an area of engineering practice*". [30] However, by the 1990's AACE dropped "profitability" from its definition of Cost Engineering; the current mission statement now speaks of "managing and controlling". [31] In 2013, AACE eliminated the "Certified Cost Engineer" as a certification designation. The AACE 2014 strategic plan (in effect at this writing) includes no specific pursuit of relationships with engineering institutions beyond construction management. Indeed, a 2015 article about AACE strategic

plans speaks of "*project controls* industry experts" reaching out to employers and working with Construction Management schools to "prepare students for careers in *project controls*" (emphasis mine). [32] Today, less than 20% of respondents to the AACE salary survey describe themselves as professional engineers. [33]

While nominally representing an engineering branch per the Constitution, the current strategy, actions and words of the association emphasize "project control", a branch of project management. Mr. Wellington might say that project control focuses on the art of constructing rather than "*the art of not constructing*" (assuring that only the most profitable investments are selected for execution). For that service to profitability, the cost engineer "*is more likely to receive a greater measure of reward*" as stated by Mr. Gillette.

The original cost engineers worked with the engineering community to make profitable investment decisions first and to deliver on the decided objectives second. The following steps are recommended should AACE wish to keep the engineering of profitable solutions at the forefront:

- Emphasize in strategy, actions and words that TCM is, as the Constitution states; "*an area of engineering practice*";
- Emphasize *profitability* objectives in the AACE mission statement and strategic plan;
- Establish relationships with peer *engineering institutions* in *all* disciplines;
- Engage with *university engineering programs* beyond Construction Engineering (updating Jelen's Cost and Optimization Engineering [34] as a textbook would help); and
- Pursue student, graduate and practicing *engineers* as members (a Certified Cost *Engineer* designation for those meeting its conditions was and would be an excellent enticement).

Summary

This paper reviews the early history of the three technical interest areas of AACE International as identified at its founding in 1956; cost estimating, cost control and engineering economy (profitability). The biographies and philosophies of the early leaders (Messrs. Wellington, Gillette and Fish) were reviewed. Cost Engineering practices evolved in the field of Civil Engineering and mainly in the transportation industry in which the early leaders worked. AACE sprang from Chemical Engineering which in its formative stages provided an opening for recognition of Cost Engineering as a specific branch of practice. The history shows that Cost Engineering began as a part of engineering and TCM is still defined as "an area of engineering practice". The paper concludes by observing that the current direction of AACE strategy appears to be towards project control, a branch of project management. Recommendations for preserving and strengthening Cost Engineering by focusing on profitability and engineering interests are provided.

References

1. Morris, R. R. AACE International: 50 Years of Service and Dedication, 1956-2006, AACE International, Morgantown, WV, 2006
2. Zimmerman, O.T. and Irvin Lavine, Chemical Engineering Costs, Industrial Research Service, 1949.
3. Agricola, G, De Re Metallica (On the Nature of Metals), original 1556, translated to English by Herbert and Lou Hoover, London, 1912.
4. Institute of Civil Engineers (ICE), "Our History", https://www.ice.org.uk/about-us/our-history, Oct 28, 2015
5. American Society of Civil Engineers (ASCE), "History of ASCE", http://content.asce.org/history/150/150years.html, Oct 28, 2015
6. The Inland Waterways Association, History/Background, https://www.waterways.org.uk/waterways/history/history/background, Oct 28, 2015
7. Sutcliffe, J., A Treatise on Canals and Reservoirs, Law and Whittaker, London, 1816.
8. Jones, T, "Engineers and Their Estimates", Journal of the Franklin Institute, Franklin Institute, Philadelphia PA, Vol XXV, 1840
9. Casey, W.R., "On the Causes of the General Failure of Canals in America", American Railroad Journal and Mechanics Magazine, Vol XVII, 1844.
10. Currier & Ives, Illustration: "The Great Race for the Western Stakes", Library of Congress (http://www.loc.gov/pictures/item/2003656591), Currie & Ives, circa 1870.
11. Editor, "Memoriam; The Late Arthur Mellen Wellington", Engineering Magazine, Vol 9, No. 4, July 1895.
12. Johnson, R (editor), The 20th Century Biographical Dictionary of Notable Americans, The Bibliographical Society, Boston, 1904.
13. Wellington, A. M., Methods for the Computation from Diagrams of Preliminary and Final Estimates of Railway Earthwork, D. Appleton & Company, New York, 1874
14. Wellington, A. M., The Economic Theory of the Location of Railways, 2nd edition, 1887
15. "About Us", Engineering News-Record (ENR), http://enr.construction.com/aboutUs/contact/aboutus.asp, Oct 28, 2015.
16. Obituary, Halbert P. Gillette, New York Times, June 20, 1958.
17. "Who We Are" (History of Scranton Gillette Communication), http://www.scrantongillette.com/content/who-we-are, Oct 28, 2015
18. Gillette, H. P. and R. Dana, Handbook of Mechanical and Electrical Cost Data, McGraw-Hill, New York, 1918.
19. Gillette, H. P., Handbook of Construction Costs, McGraw-Hill, New York, 1922
20. Gillette, H. P. and R. Dana, "Cost Keeping and Management Engineering", Myron C. Clark Publishing Company, 1909.
21. Gillette, H. P., Climatic Cycles Reflected in Geological Data, Geological Publishing Company, 1937
22. Williams, H., C. Oglesby and F. Terman, Memorial Resolution; John C.L. Fish, 1870-1962. Stanford Historical Society, 1962.
23. Fish, J., Engineering Economics: First Principles, McGraw-Hill, New York, 1915.

24. Burton, Francis, Engineering Estimates and Cost Accounts, The Technical Literature Company, Manchester, England, 1896.
25. Frost, H., "The Literature of Methods and Costs in Technical Work", Technical Literature, The Technical Literature Company, New York, 1907
26. Denham, R.S., The A-B-C of Cost Engineering, The Denham Cost Finding Company, Cleveland, OH, 1919.
27. Petroski, H., An Engineers' Alphabet; Gleanings From the Softer Side of a Profession, Cambridge University Press, 2011.
28. Walker, W.H, W. Lewis and W. MacAdams, Principles of Chemical Engineering, McGraw Hill, 1923.
29. National Academy of Sciences, Scientific and Technical Societies of the United States and Canada, 1960-61, 1961. National Academy of Sciences, Washington DC, 1961.
30. AACE International, Constitution, Article I, Section 3, July 1, 2014.
31. AACE International, "Our Mission", www.aacei.org, Feb, 2016.
32. Owen, Julie, "President's Message: Strategic Priorities", The AACE International Source, October 2015.
33. AACE International, 2014 Salary and Demographic Survey of Project and Cost Professionals - Raw Data, 2014.
34. Humphreys, Ken, Jelen's Cost and Optimization Engineering, 3rd Edition, McGraw-Hill, 1991.

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