A Continuance of Marginal Cost Methodology in Project Change Management

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Abstract: Change management is an inevitable part in the engineering management of engineering projects so effective change management is critical to determine if the proposed changes add economic value to the project. The marginal cost methodology is proposed to effectively manage change and to parse the changes only to those which add economic value. The marginal cost methodology is valuable in engineering decision making and also facilitates statistical analysis in trade studies for applications to future projects.

Keywords: project change management, engineering economics, life cycle costing, marginal costs

Introduction

Engineering changes ("changes") to project scope are inevitable: the more complex a project is and the longer the project lasts, the more changes can be expected. Changes are defined as adjustments to the original plan and could include additions, deletions, substitutions, repurposing, amongst others. Engineering changes can easily number in the hundreds or the thousands for large projects so effective change management is crucial for the project to stay on schedule and to minimize cost overruns.

This paper will focus on the engineering life cycle cost of initial construction only. It will not cover the project once the equipment, building or facility is put into operations and the associated costs from that point on. Again the focus is only on the engineering project costs before the project begins normal operations.

Often changes are handled on an ad hoc basis and change management tracking systems aren't as robust as necessary to handle complex engineering changes. However, a more important question needs to be addressed – do the proposed engineering changes add value to the project? Large changes will warrant further engineering economic analysis but smaller changes should be tracked and evaluated also especially if there are numerous smaller changes implemented. It is imperative then to carefully track all relevant changes to determine if additional engineering economic analysis should be performed.

Outstanding project management software such as "PROJECTMANAGER", "Microsoft Project", and "Easy Projects" can skillfully manage project changes and provide a repository for all projects, both past and present. Engineering project cost changes can be stored and easily accessed, so this advantage enables effective use of the engineering project cost changes for better engineering decision making.

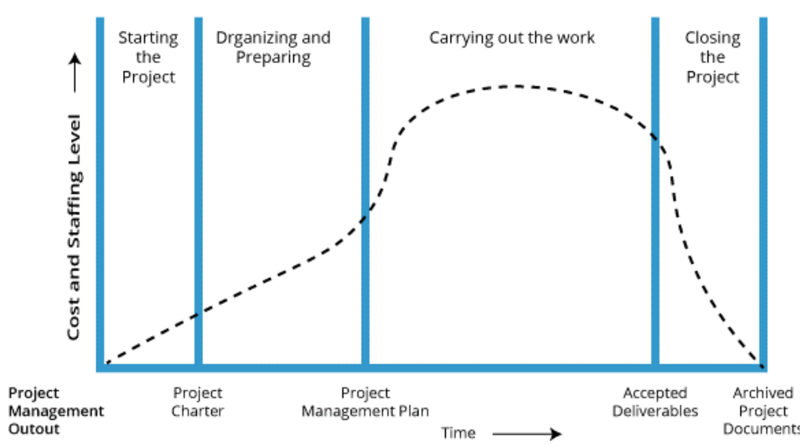


Figure 1.Project Summary

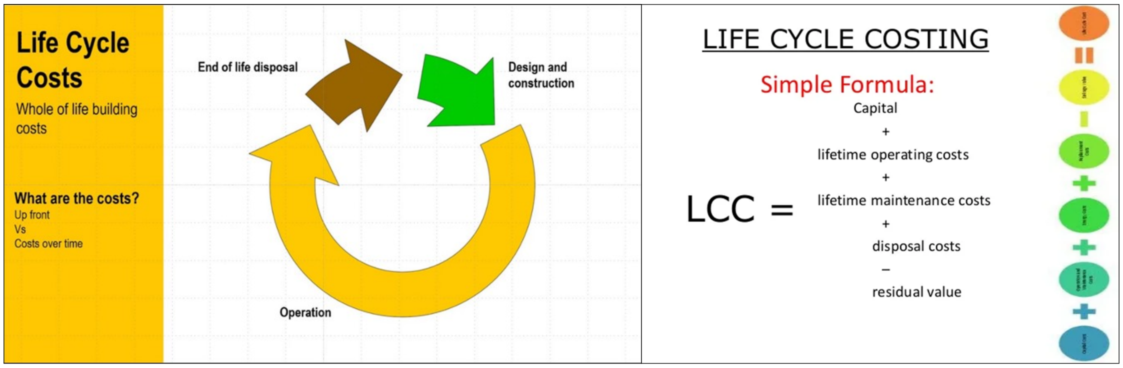


Figure 2.Overview of Life Cycle Costing

Life Cycle Cost Analysis

Life cycle cost analysis studies all costs throughout the lifetime of a project, from inception (including research & development) through the completion of the project. The life cycle cost analysis is parsed into three arbitrary sections: (1) project inception, (2) project operations and (3) project completion. This analysis is done before the project is started and is part of economic feasibility study of the project.

The primary difficulty with life cycle cost analysis is the uncertainty of future costs and the secondary difficulty is future technology. Life cycle cost analysis is time intensive and it's helpful to have experience with these studies (which obviously takes time acquire). The longer the life of the project, the more uncertain the costs are. Finally, technological advances are difficult to anticipate and forecast but could be critical to the success of a project. Project risk will greatly increase if the project involves evolving or cutting-edge technology at any phase.

The effectiveness of life cycle cost analysis is based on the accuracy of the cost inputs into the analysis. Generally acquisition costs are the most accurate forecast but these are only the "tip of the iceberg" and many other costs must be carefully analyzed and incorporated into the life cycle cost analysis. Each project has its own particular costs that are unique to the project and it is dangerous to omit any important cost.

Trade studies of previous projects can mitigate the error of omitting critical costs. Trade studies are a lot of work and it's difficult to see immediate benefits, but the project manager with foresight understands that trade studies are a best practice. Trade studies can be a guide to identify all relevant costs based upon previous projects.

Figure 3. Difficulties of Life Cycle Costing

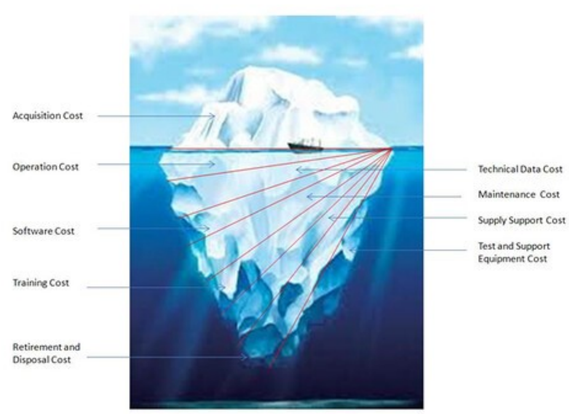


Figure 4. All Relevant Project Costs

Managing Project Change

Once the project has commenced, cash outflows associated with the costs are now expended. As the project progresses these actual costs are accumulated and are compared to committed or budgeted project costs as a cost control mechanism.

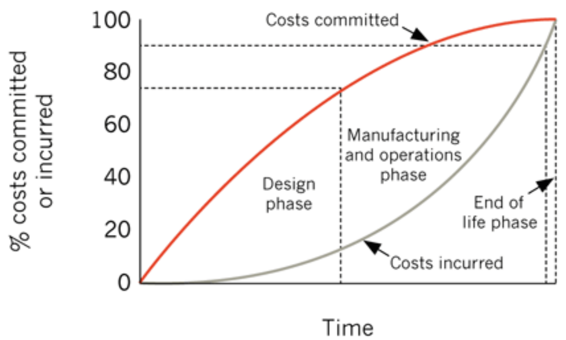


Figure 5.Comparison of Actual Costs to Committed Costs

The project manager and project team gain experience and knowledge as the project progresses so they may propose or institute changes that improve the probability of successful project completion. There could be many proposed improvements and the key is to identify those changes that add economic value to the project. Some proposed improvements could involve increased reliability, cost cutting, process efficiency, etc. Successful project change management includes the proficient administration of these proposed changes. The analysis of the proposed changes could be time-consuming and intense but the larger the proposed changes and its corresponding benefits, the greater the need for this analysis. Finally, as the project progresses, changes will be more difficult to implement, even if the changes are warranted.

The graph above again compares committed costs to actual costs but adds the ease to implement project changes (yellow line). It is important to note the inverse relationship between costs incurred versus ease of change – over time, as project costs accumulate, the ability

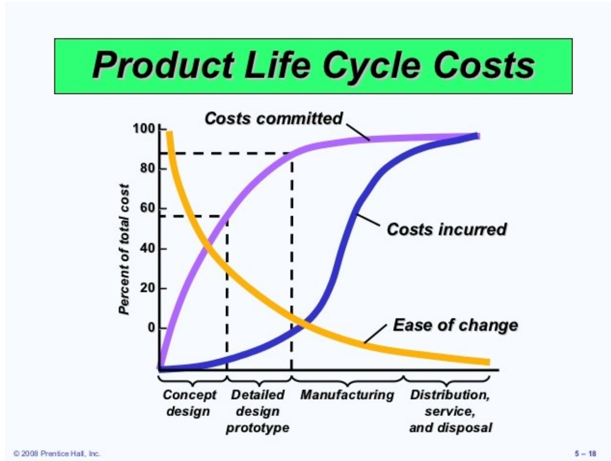


Figure 6. Ease of Implementing Project Changes

to implement changes becomes more difficult. Project changes are relatively easy to execute early in the project's life but becomes more difficult to apply as the project progresses. Finally, the larger the cost of the proposed changes, the greater the need for engineering economics to determine the economic benefits of proposed change to the project.

Overview of Methodology

The marginal cost methodology from microeconomic theory can be applied to the engineering economics of engineering project cost changes. The benefit of the marginal cost methodology is that it can track engineering project cost changes and it can determine the incremental benefits of these changes.

Is the engineering project cost change a change to an existing cost or is it a new additional cost altogether? Is the engineering project cost change a substantial betterment? Does the engineering project cost change alter the project scope? These

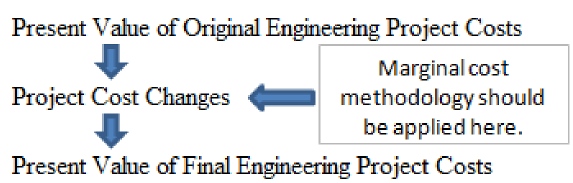


Figure 7. Schematic of Marginal Cost Methodology

are the types of issues that the marginal cost methodology can address in regards to engineering project cost changes. In almost every case the engineering project cost change needs to add economic value for the engineering project cost change to be warranted.

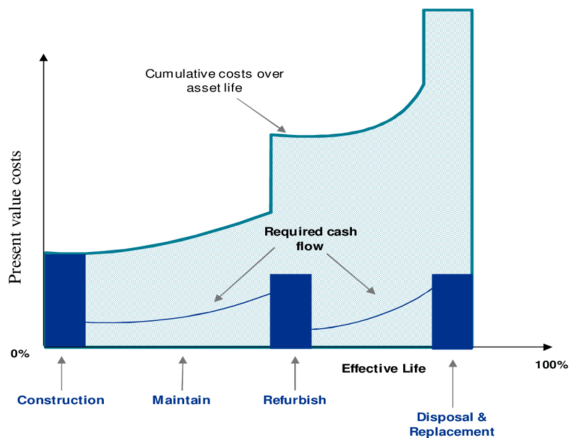


Figure 8. Present Value of Project Costs

Any engineering project cost change that can be eliminated is beneficial especially if this elimination in no way hurts the project scope. It should be investigated why this cost was included in the original analysis but if an engineering project cost can be legitimately eliminated it can only be an advantage to the project.

Time must be a major consideration when estimating the costs of a project. Some US Navy super aircraft carriers take four or more years to construct. Here in the Los Angeles area freeway and highway widening projects progress slowly for around a decade with no completion in sight for the foreseeable future. An article in the *Business Insider* describes how a project to update the US Air Force C-5M Super Galaxy cargo planes took 17 years to complete.

Because of the long timeframes involved time becomes critical in the time value of money component of the engineering economic analysis. Engineering economic analysis must employ the present value methodology to accurately measure the economic value added of an

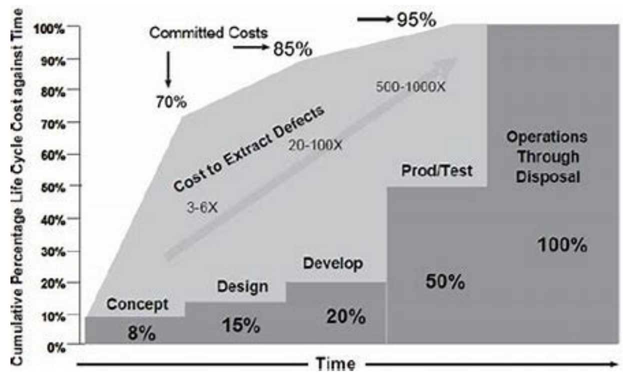


Figure 9. Time as a Critical Component in Engineering Economics

engineering project cost change. Not only is the dollar amount of the engineering project cost change important but the timing of the engineering project cost change is also crucial.

For the purposes of this paper engineering project cost changes will be categorized into three general groupings but there are no conventions that say that these must be the categories. The categories are created based on their timing during their construction cycle and include (1) investment costs, (2) operating costs and (3) terminal costs. Investment costs include engineering design and planning, procurement costs of materials and equipment, licensing and permitting costs, feasibility studies, etc. Operating costs could include construction labor, ongoing procurement costs, supervision, engineering and construction overhead, etc. Terminal costs include disposal costs, inspections, testing, cost of removal, reliability and maintainability estimates, trade studies and documentation, etc. This list is by no means comprehensive and there are many relevant costs and expenses that have been unintentionally omitted.

Committed costs are those cash flows budgeted to the project. Both Figure 5 and Figure 6 show the general pattern of committed costs. Committed costs are low during the project planning stage but hit the maximum once there is the decision to undertake the project. Variance analysis should be conducted between committed costs versus actual costs throughout the project.

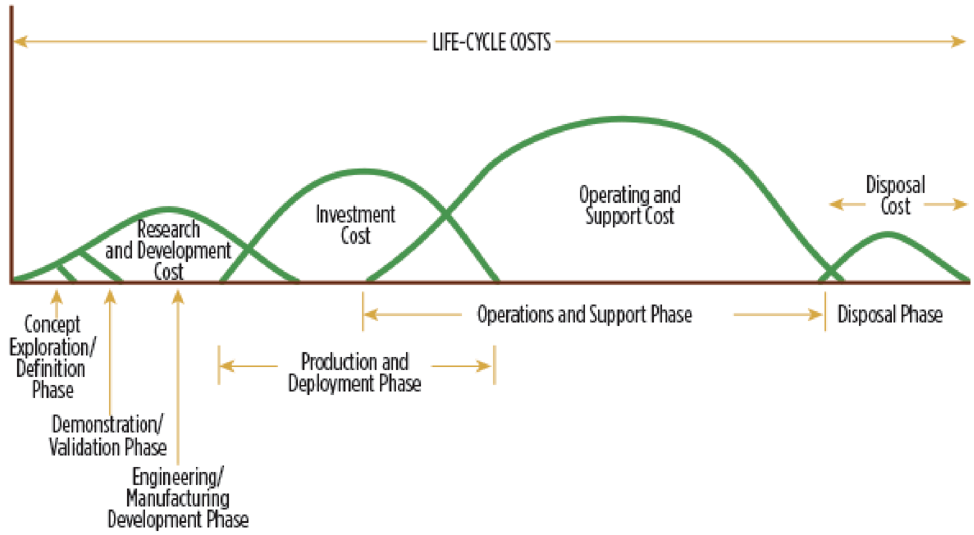


Figure 10. Summary of Life Cycle Costs

Cost control measures should be employed during the project. Ideally actual costs of the project will be at or below committed costs at project completion – the project is over budget if actual costs are greater than committed costs.

Methodology Explained

The general cost function is:

engineering project cost = f(a1, a2, a3)

where a1 is the investment costs, a2 is the operating costs and a3 is terminal costs. Engineering project cost is abbreviated as EPC.

The marginal costs are the following differential equations:

$\partial EPC \div \partial a1 \qquad \partial EPC \div \partial a2 \qquad \partial EPC \div \partial a3$

The objective is to minimize the engineering project cost so it is imperative to understand the underlying structure of the individual costs that constitute the total engineering project cost.

The equation for the engineering project costs is:

$$\text{Present Value of Original Engineering Project Costs} = \sum_{t=0}^{n} \frac{\text{Investment Costs}}{(1+i)^t} + \sum_{t=0}^{n} \frac{\text{Operating Costs}}{(1+i)^t} + \sum_{t=0}^{n} \frac{\text{Terminal Costs}}{(1+i)^t}$$

where i is the hurdle rate used in engineering economics.

The original engineering economics of the engineering project costs contains valuable information imperative for the current project but also to future engineering economics and trade studies. It would be wasteful to discard this information especially as this information can add insight to the final analysis and future trade studies.

The equation for the marginal cost of engineering project cost changes is:

$$\text{Marginal Cost of Engineering Project Cost Changes} = \sum_{t=0}^{n} \frac{\text{engineering project cost changes}}{(1+i)^t}$$

where i is the hurdle rate used in engineering economics and engineering project cost changes are segregated into investment costs, operating costs and terminal costs.

If the engineering project cost change is warranted, feasible and adds economic value, the marginal cost of the engineering project cost changes should be added to the present value of original engineering project costs:

$$\text{Present Value of Final Engineering Project Costs} = \text{Present Value of Original Engineering Project Costs} + \text{Marginal Cost of Engineering Project Cost Changes}$$

The benefit of this approach is that it is straightforward to track various engineering project cost changes to determine economic value added. Instead of updating the present value of original engineering project costs, keep this intact and add the marginal cost of the engineering project cost change to keep the engineering economics updated and integral in engineering decision making.

This marginal cost methodology will help to discern the trend of engineering project cost changes, the timing of engineering project cost changes and determine the incremental economic value added of the engineering project cost changes.

Financial Example

The present value of original engineering project costs was calculated to be $75 million for construction that will last for 3 years. The hurdle rate is 8%. The first engineering project cost change is an increase in Year 1 material costs of $8 million. Labor rate savings are estimated to be $4 million in Year 2 and $2 million in Year 3.

$$\text{Present Value of Final Engineering Project Costs} = \underset{\text{(in \$millions)}}{\$\ 75} + \frac{8}{(1+8\%)^1} - \frac{4}{(1+8\%)^2} - \frac{2}{(1+8\%)^3} = \$\ 77.4 \text{ million}$$

The present value of final engineering project costs is updated to $77.4 million.

The marginal cost of engineering project cost changes is calculated as follows:

$$\text{Marginal Cost of Engineering Project Cost Changes} = \underset{\text{(in \$millions)}}{\frac{8}{(1+8\%)^1}} - \frac{4}{(1+8\%)^2} - \frac{2}{(1+8\%)^3}$$

The marginal cost of engineering project cost changes is $2.4 million.

Again, the present value of original engineering project costs remains intact and the incremental engineering project cost changes are added to this amount. The marginal cost methodology can track the level and timing of engineering project cost changes to determine the economic value added of these changes.

Statistical Analysis and Trade Studies

Statistical analysis of engineering project cost changes should be performed to support trade studies. A particular engineering project cost change could make a large difference in a single project but in the long-run which engineering project cost changes are statistically significant? It would aid in engineering decision making to understand which of the individual engineering project cost changes drive the marginal cost of engineering project cost changes in the long-run.

Descriptive statistics are imperative but inferential statistics, particularly regression analysis, should be the statistical tool of choice. The general equation for the regression equation in matrix notation is:

$$\boldsymbol{\beta = (X'X)^{-1}X'Y}$$

where β is the regression coefficients, Y is the dependent variable and X are the independent variables.

In the marginal cost methodology the present value of final engineering costs would be the dependent variable. In this paper the three main engineering project cost changes are categorized into (1) investment costs, (2) operating costs and (3) terminal costs so these would be the independent variables. If the project management system carefully tracked and correctly categorized the engineering project cost changes then the setup of a multiple regression analysis for trade studies should be straightforward. If the independent variables are independent of each other then the multiple regression analysis should provide useful results.

The multiple regression equation where the present value of final engineering project costs is the dependent variable is:

$$\text{Present Value of Final Engineering Project Costs} = \alpha + \beta_1\text{investment cost} + \beta_2\text{operating costs} + \beta_3\text{terminal costs} + \varepsilon$$

where α is the intercept and ε is the error term.

Appropriate regression tests should include ANOVA, t-statistics, correlation analysis and goodness-of-fit (r^2) diagnostics.

Regression analysis can help to determine which of the independent variables (investment costs, operating costs, terminal costs) are statistically significant to plan for regarding engineering project cost changes for engineering decision making.

Was it a change in the level of proposed output of a project once in operation that warranted such as change? If that is true, regression analysis can be implemented to parse cost changes into their fixed and variable component to ultimately perform cost-volume-profit analysis. Linear regression is particularly useful to supplement cost-volume-profit analysis and the linear regression equation is:

$$\text{Engineering Project Cost Changes} = \alpha + \beta(\Delta \text{ in level of ouput}) + \varepsilon$$

where α is the intercept and ε is the error term.

Appropriate regression tests should include ANOVA, t-statistics, correlation analysis and goodness-of-fit (r^2) diagnostics.

Here α can be interpreted as total fixed costs and β as the variable cost per unit. If these two coefficients are statistically valid then cost-volume-profit analysis can be implemented to provide valuable insight into the effects of changes in the level of proposed output. This could explain why an engineering project cost change was necessary.

Case Study - Statistical Analysis

An aerospace subcontractor in the Los Angeles area (which requested anonymity) implements the marginal cost methodology in project change management and has kept accurate records of the present value of original engineering project costs, the present value of final engineering project costs, marginal cost of engineering project changes and engineering project cost changes, which was further segregated into investment costs, operating costs and terminal costs. Regression analysis was performed where the present value of final engineering project costs is the dependent variable and the independent variables are investment costs, operating costs and terminal costs. The table used in the regression analysis follows (in $thousands):

PV Final Engr	Investment	Operating	Terminal
$ 3,471	$ 260	$ 442	$ 23
2,979	225	459	21
4,195	275	478	20
4,701	235	438	19
3,471	240	444	22
3,960	195	379	21
4,701	235	379	20
4,701	265	379	19
3,311	230	386	24
4,664	235	539	17
4,605	302	483	19

Multiple regression analysis was performed and the regression equation is:

			(t-statistics)
PV Final Engr. =		11672	(5.99)
		+ 6.3Investment	(1.66)
		- 5.98Operating	(-2.62)
		- 319Terminal	(-5.63)

$r^2 = .838$ F-calculated = 12.07

Full results are shown in the appendix.

Regression diagnostics for this dataset are generally good but the investment costs are statistically insignificant at the .05 level of significance. A larger sample size could change this conclusion but as of now investment costs do not add explanatory value to the present value of final engineering project costs. Data for investment costs should not be discarded and should be updated along with future additions to operating costs and terminal costs as it could be statistically significant with a larger sample size.

The statistical analysis yields a key insight: the negative coefficients on some of the project changes, specifically changes to operating costs and terminal costs.

PV Final Engr. = 11672
+ 6.3Investment
- 5.98Operating
- 319Terminal

The subcontractor only instituted changes after careful analysis that included the economic benefits of the changes and the timing of the changes. The negative coefficient implies that changes <u>decreased</u> the overall cost of the project. This conclusion is statistically significant. The subcontractor indicated that the project scope remained the same for all of the projects in the statistical analysis. The project remained the same but project costs decreased due to changes which were carefully implemented. Basically, the subcontractor made the right changes at the right time. The changes had the direct economic benefit of decreasing total project costs because of the utilization of effective project change management.

In the case of changes to operating costs, an increase of $1 decreased the total project cost by approximately $6. This is a favorable benefit/cost ratio and shows the advantages of efficient project change management. The subcontractor indicated that changes were handled on an ad hoc, case-by-case basis because each project was unique, but the subcontractor followed the principles of project change management for each and every change. Unfortunately a "one size fits all" is inapplicable for aerospace subcontracting, but a disciplined approach to project change management can generate substantial benefits for a project. The type of project really doesn't matter.

Other statistical tests can be performed beyond the regression analysis presented in this case study.

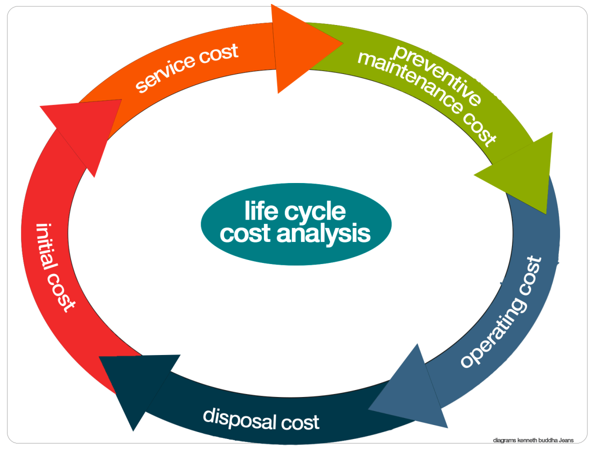
Limitations and Constraints

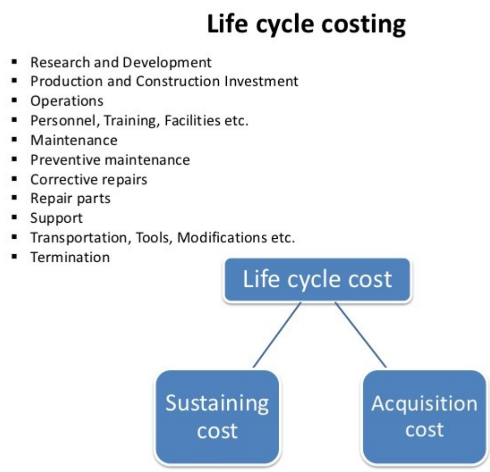
Obviously, a larger sample size with favorable results would add greater credence to the statistical analysis just presented. The constraint to consider is that the data used in the statistical analysis is not public data and the anonymous subcontractor was kind enough to allow the authors to use its data. Additional studies in this area would therefore depend on other subcontractors to provide data for further analysis. In the hypercompetitive environment of aerospace subcontractors in the Los Angles area, competitors are unlikely to pool data for analysis and cooperate with each other. The aerospace subcontractors generally are unwilling to work with competitors, which make data acquisition difficult at best.

The subcontractor the authors worked with follows the concepts of the Project Management

Institute (PMI) and its project cost accumulation was configured to facilitate statistical analysis. Companies are not required to configure their cost data in this manner. If the authors received data from other subcontractors whose computer architecture does not facilitate statistical analysis, the authors would be required to rearrange the cost data – this could introduce translation errors. Project costs must be configured by the subcontractor's computer architecture, not the authors. The authors could reconfigure the data but that could be an error-prone process.

The authors chose only three project cost categories: (1) initial investment (including R&D), (2) operations and (3) termination. A finer breakdown could have been used that would have introduced additional cost categories, although total project cost would remain unchanged. A finer breakdown of cost categories could have been implemented but again the authors studied the cost categories currently in use by the subcontractor. The subcontractor has over a dozen years of experience and these three cost categories were more than adequate for the subcontractor. Again the authors could have added additional cost categories in an attempt to derive additional intuition of project costs and this is something that the authors must consider. The graphics on the right are suggestions for the further dichotomy of costs.





Conclusion

The marginal cost methodology in project change management is a technique to successfully manage changes to project scope in the construction of projects. This is especially important for very expensive projects and projects which will take an extended period to complete. It facilitates both engineering economics and statistical analysis. The conclusions in the marginal cost methodology provide valuable insight to both current and future large-scale engineering projects but is equally beneficial to small or medium-sized projects that must contend with numerous changes.

Project changes that are subjected to feasibility reviews, that are analyzed by employing disciplined quantitative techniques and that are implemented on a timely basis add economic value to a project.

Appendix: Regression Results

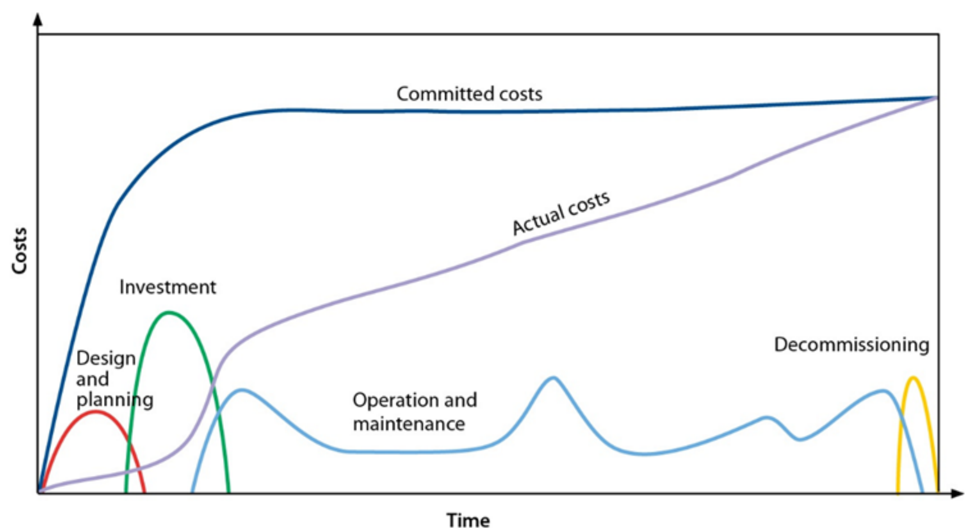
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.915443256
R Square	0.838036354
Adjusted R Squa	0.768623363
Standard Error	317.0777276
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	3641454.003	1213818.001	12.07319179	0.003721247
Residual	7	703767.9973	100538.2853		
Total	10	4345222			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	11672.4257	1949.059081	5.988749041	0.000548381	7063.633333	16281.21807	7063.633333	16281.21807
Investment	6.268066369	3.766390671	1.664210359	0.140017229	-2.63803235	15.17416509	-2.63803235	15.17416509
Operating	-5.980690111	2.284299167	-2.618172872	0.03450074	-11.38219932	-0.579180905	-11.38219932	-0.579180905
Terminal	-319.1087158	56.69490629	-5.628525324	0.000791997	-453.1708661	-185.0465655	-453.1708661	-185.0465655



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