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MAADI™ group

Cost and Lifespan Considerations for Engineers

Aluminum is the Durable, Maintenance-Free Material Choice for Structural Building Projects.

Prepared by

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The document objective is to provide a quantitative analysis on Total Cost of Ownership (TCO) between Aluminum and Steel.

The document was prepared by Deloitte inc. with the help of the MAADI Group and the Aluminum Association of Canada (AAC). All the information contained within this document was provided by MAADI Group or a third party[7] (Study sponsored by the CQRDA). All financial modeling was performed by Deloitte based on the data provided.

Project Lifespan: Examining the Real Total Cost of Ownership

Costly project decisions tend to rely on existing practices, rather than exploring new opportunities for long-term cost savings. Often the process for making investment decisions is not updated when new processes, materials or benefits are available in the marketplace. Evaluation criteria often don't take into account a time frame that represents the project's actual lifespan. This hinders the use of alternative processes and/or material choices that could realize significant cost benefits over the project lifespan. These factors are clearly evident when selecting the right material for a bridge. Steel has previously been the preferred material choice, without considering how alternative materials and processes will impact the bridge's total cost and lifespan.

This document provides decision makers with a TCO framework to compare the material selection of aluminum vs. steel over the lifespan of the project. Each project presents unique challenges; however, the methodology and the project selected will demonstrate the importance of having an integrated long-term view of costing for major civil engineering projects. This integrated approach demonstrates that over a project's lifespan, aluminum is a valid, cost-effective alternative to steel.

Evaluating True Project Cost

Though it dates back to the first quarter of the twentieth century, the Gartner Group helped popularized the TCO method in the mid-1980s[1]. The TCO approach was quickly adopted by the computer hardware, software, and transportation industries when they faced evaluating multiple solutions that often differed greatly in both benefits and cost structure. Importantly, the TCO approach provides a sustainable evaluation through its consideration of the total costs over a project's full life cycle.

For example, when purchasing a new bus, the acquisition cost might be attractive; however, the product might suffer from poor reliability coupled with expensive repairs. Only by considering the cost over the complete lifespan of the bus is it possible to adequately evaluate all alternatives. This TCO methodology should also be applied to large civil engineering projects.

Figure 1. This rusted steel bridge beam requires costly maintenance, compared to a corrosion-free aluminum bridge.

TCO for Civil Engineering Projects

When evaluating a civil engineering project, four cost categories must be considered:

Acquisition	Installation	Maintenance and operations	Disposition
Often the largest up-front costs in a project, acquisition costs can include materials, parts, land, etc. Acquisition costs are often disbursed well before the structure is functional.	Sometimes included with the acquisition costs, the installation costs represent all fees (including transport) to make the assets functional. Installation costs vary greatly, based on location, regulatory, project timeline, weather, and other project-specific constraints.	Maintenance costs are the annual expenses required to maintain the assets safety and functionality over its expected lifespan.	Too often neglected, the disposition is all the costs and revenues associated with the deconstruction, removal, salvaged materials/recycling, and site remediation.

Table 1. Cost categories for civil engineering projects.

When compared to other industries, many civil engineering projects have a relatively high cost of acquisition. Nonetheless, the maintenance and operation of a structure must be considered when investing in any civil engineering project. The TCO methodology provides a way to evaluate alternatives, taking into account all costs in a project over its lifetime. It is often the preferred method in order to evaluate alternatives by public agencies.

Figure 2. This aluminum bridge retains structural strength and corrosion resistance, even in extreme climate conditions.

The Benefits of Aluminum

For many civil engineering projects, steel and concrete remain the materials of choice; however in some projects, other materials such as aluminum offer benefits worth consideration. When it comes to replacing steel, aluminum provides the same benefits at a lower TCO. The benefits of aluminum include [2]:

Lightweight

Aluminum weighs less by volume than most other metals. It is about one-third the weight of steel, iron, copper, or brass. Aluminum's lighter weight reduces transportation and manipulation costs, and by replacing steel, extends the life and maximizes the load-bearing capacity of bridges.[3-4]

Strong

Aluminum profiles can be made as structurally strong as needed for most applications. Cold-weather applications are particularly well-served by aluminum because, as temperatures fall, aluminum actually becomes stronger.

Non-corrosive

Aluminum naturally generates a protective oxide coating and is highly corrosion resistant, greatly reducing maintenance costs and retaining an aesthetically pleasing, rust-free appearance.

Conducts heat and electricity

Based on weight and overall cost, aluminum conducts heat (and cold) better than other common metals, and pound-for-pound, aluminum is twice as electrically conductive as copper.

Resilient

Aluminum combines strength with flexibility, and can flex under loads or spring back from the shock of an impact.

Recyclable

Aluminum retains a high scrap value, and can be recycled and reused indefinitely without losing any of its superior characteristics, making its disposition a revenue-generating possibility. The re-melting of aluminum requires little energy: only five percent of the energy required to produce the primary metal initially is needed in the recycling process.

Accepts finishes

Aluminum can be permanently finished using a variety of common techniques, including liquid paint, powder coatings, anodizing, or electroplating.

Seamless

Complex aluminum shapes can be produced in one-piece extrusions without using mechanical joining methods. Such parts are made stronger and less likely to leak or loosen over time, potentially increasing the structure's lifespan and reducing installation costs.

Aluminum versus Steel: Characteristic and Cost Comparisons

For many civil engineering projects, aluminum and steel are valid options for material selection. This study specifically compares aluminum to three types of steel protective finishes. The following table provides an overview of aluminum and steel types used for comparison.

Material	Steel – 2 coats	Steel – 3 coats	Steel – Hot-dip galvanized	Aluminum – Natural finish
Characteristics	CSA G40.21 grade 350W (ASTM 50W), Standard commercial blast SSPC-SP-6, 2-layers 125μm Hi-Build Epoxy	CSA G40.21 grade 350W (ASTM 50W), Blast near white SSPC-SP-10, 1-layer 65μm Zinc Rich Epoxy, 1-layer 100μm Hi-Build Epoxy, 1-layer 50μm Polyurethane	CSA G40.21 grade 350W (ASTM 50W), Standards CSA G-164 and ASTM-123, 87μm thickness	Aluminum natural finish, 6xxx and/or 5xxx alloys

Table 2. Aluminum vs. Steel finish/coating characteristics.

In order to accurately compare a typical project, a pedestrian bridge was selected. The project has the following characteristics [5]:

Model	Pony Truss Warren
Overall length (single span)	70 feet – 21.3 m
Clear width	6 feet – 1.8 m
Weight	Aluminum: 6,846 pounds – 3,112 kg Steel: 11,000 pounds – 5000 kg
Weight ratio aluminum/steel	62%
Bridge deck	Southern Yellow Pine (SYP) 38 mm
Applicable code	S6 – 06 (2nd Supplement)

Table 3. Pedestrian Bridge description.

Figure 3. This aluminum bridge depicts a typical pedestrian aluminum bridge in an urban environment.

The analysis was conducted in two environments, urban and maritime. The urban environment represents the most common environment for such a project, while the maritime environment clearly demonstrates aluminum's corrosion resistance benefits.

Costs associated with the project are the following [6]:

Material	Steel – 2 coats	Steel – 3 coats	Steel – Hot-dip galvanized	Aluminum – Natural finish
Installation	See Note*	See Note*	See Note*	See Note*
Acquisition [5]	$26,875	$29,690	$26,938	$30,979
Maintenance [7]	See appendix for maintenance schedule for Urban and Maritime environment	See appendix for maintenance schedule for Urban and Maritime environment	See appendix for maintenance schedule for Urban and Maritime environment	None
Disposition value in 50 years based on a 2% inflation rate	$997	$997	$997	$15,793

*Note: Installation costs are not specifically considered in this analysis due to variability based on localization, weather, supplier's proximity, and design. However, due to its lighter weight, aluminum provides important savings over steel in transportation and manipulation during installation, as seen in the example below.

Table 4. Costs associated with the bridge project.

Installation

As mentioned above, installation costs have not been specifically considered in this analysis as variability occurs based on localization, weather, supplier's proximity, and design. However, due to its lighter weight, aluminum provides important savings over steel in its transportation and manipulation during installation. Aluminum's advantage over steel becomes even more important as the size and weight of the bridge increases. A recent project [8] highlighted this dynamic where two identically sized bridges were considered: the steel structure weighed 60 percent more than the aluminum structure, and its increased weight required a larger crane, resulting in an increase in manipulations costs of more than 200 percent.

Methodology

The methodology used to evaluate the TCO is the discounted cash flow. The discounted cash flow has many benefits, including [9]:

- Most sound method of valuation;
- Forward-looking; evaluates the cost over the lifespan of the project;
- Incorporates the time value of money to evaluate acquisition, maintenance, and salvage costs equally;
- Inward-looking, relying on the fundamental expectations of the business or asset, and is influenced to a lesser extent by volatile external factors;
- Relies on cash flow and is less affected by accounting practices and assumptions;
- Allows different components of a business or synergies (cost) to be valued separately.

In some cases, taxation, subsidies and accounting practices may benefit acquisition cost over maintenance expenses, given that:

- Many civil engineering projects are initiated by governmental agencies;
- Taxation and subsidies may vary greatly both over time and geographically. This is why cash flow or out-of-pocket expenses remain the best way to value a project.

For the discounted cash flow, the following assumptions were used:

Inflation rate of 2.0%	Discount rates of 3.0% and 6.0%	Lifespan of 50 years
The inflation rate is based on most central bank inflation targets. Steel and Aluminum prices could vary greatly in the future, based on developing country demand and increased provisioning challenges, but it is doubtful than the average price inflation will be lower.	Two discount rates will be evaluated. The 3% discount rate represents the borrowing rate for most civil engineering projects financed by governmental agencies. The 6.0% discount rate represents the borrowing rate and an additional amount representing the opportunity cost and risk (3.0%) associated with completing such a project. The discount rate required to make steel and aluminum equal in NPV will be calculated.	Civil engineering structures may last more than 50 years, but given the time value of money, any amount above 50 years will be almost immaterial to the decision.

Table 5. Discounted cash flow assumptions.

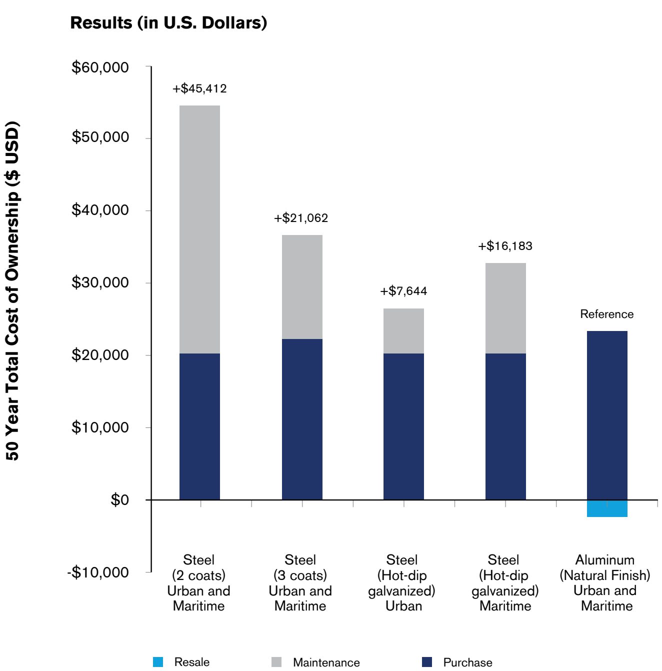
Results (in U.S. Dollars)

The present value (PV) for each cost and the Total Cost of Ownership (TCO) for each option is provided in the following tables:

Material	Steel – 2 coats	Steel – 3 coats	Steel – Hot-dip galvanized	Steel – Hot-dip galvanized	Aluminum – Natural finish
Setting	Urban & Maritime	Urban & Maritime	Urban	Maritime	Urban & Maritime
PV: Acquisition	$26,875	$29,690	$26,938	$26,938	$30,979
PV: Maintenance	$46,040	$18,875	$8,209	$16,747	$0
PV: Disposition (salvage value)*	- $234	- $234	- $234	- $234	- $3,711
TCO	$72,681	$48,331	$34,913	$43,451	$27,268

*Since all calculations are based on cost, disposition value is considered a negative value.

Table 6. PV and TCO for an urban and maritime setting with a 3% discount rate.



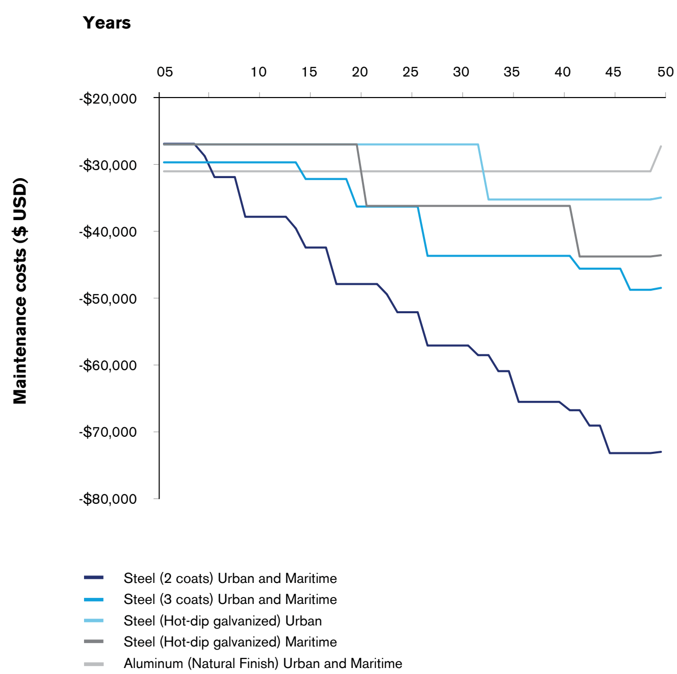


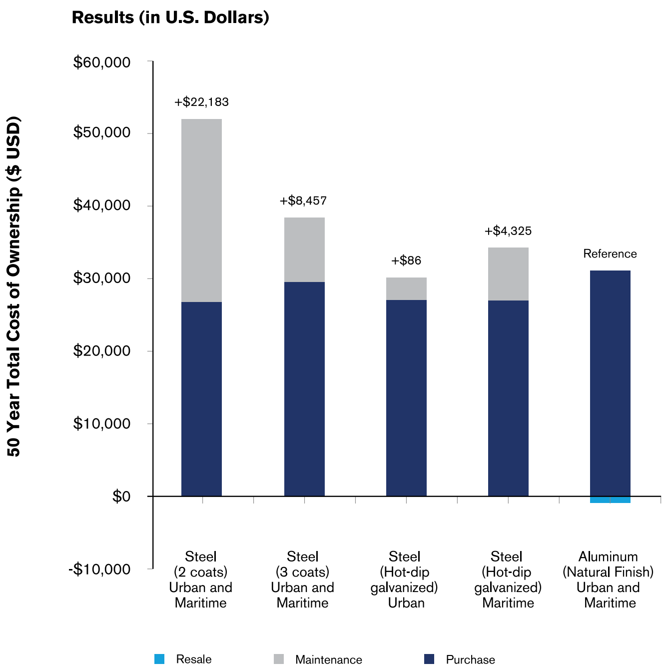
Chart 1 - Left. PV and TCO for an Urban and Maritime setting over a 50-year period, using a 3% discount rate.
Chart 2 - Right. Comparison of maintenance costs for aluminum vs. steel over a 50-year lifespan using a 3% discount rate.

Using a three percent discount rate, aluminum has a better TCO than all other steel options by more than $7,000 for an urban environment, and by more than $16,000 for a maritime environment. From Chart 2, we clearly see that aluminum has a TCO equivalent to galvanized steel after 33 years in the urban environment, and after 21 years in the maritime environment.

Material	Steel – 2 coats	Steel – 3 coats	Steel – Hot-dip galvanized	Steel – Hot-dip galvanized	Aluminum – Natural finish
Setting	Urban & Maritime	Urban & Maritime	Urban	Maritime	Urban & Maritime
PV: Acquisition	$26,875	$29,690	$26,938	$26,938	$30,979
PV: Maintenance	$25,435	$8,894	$3,276	$7,514	$0
PV: Disposition (salvage value)*	- $57	- $57	- $57	- $57	- $909
TCO	$52,253	$38,527	$30,156	$34,395	$30,070

*Since all calculations are based on cost, disposition value is considered a negative value.

Table 7. PV and TCO for an urban and maritime setting with a 6% discount rate.



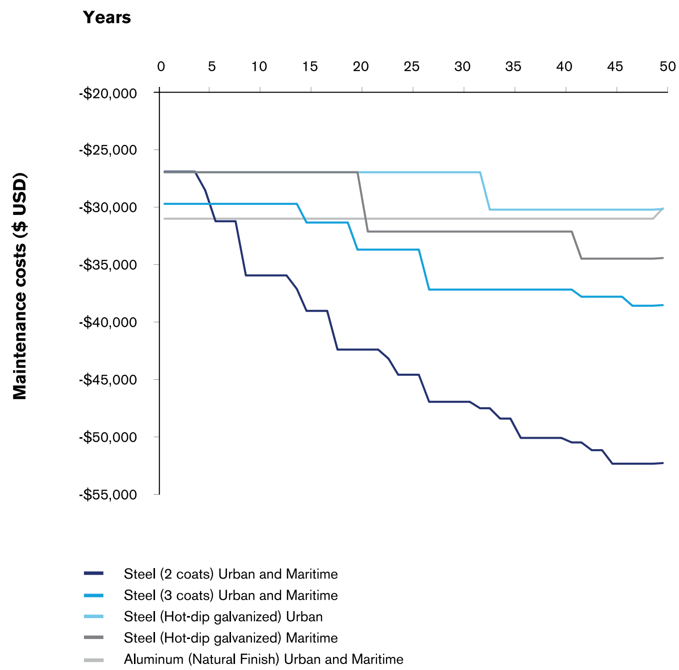


Chart 3 - Left. PV and TCO for an Urban and Maritime setting over a 50-year period, using a 6% discount rate.
Chart 4 - Right. Comparison of maintenance costs for aluminum vs. steel over a 50-year lifespan using a 6% discount rate.

When a six percent discount rate is employed, aluminum has a better TCO than all other steel options by more than $4,000 in all maritime and urban environments except Hot Dip Galvanized in an urban setting. In this case (Hot-Dip Galvanized Urban), both aluminum and steel are close to being equal in TOC at the end of 50 years. From Chart 4, we clearly see that aluminum has a TCO equivalent to galvanized steel after 50 years in the urban environment, and after 21 years in the maritime environment. A summary of the break-even time for steel structures compared to aluminum structures is contained in Table 8.

Material	Steel – 2 coats	Steel – 3 coats	Steel – Hot-dip galvanized	Steel – Hot-dip galvanized
Setting	Urban & Maritime	Urban & Maritime	Urban	Maritime
Break Even (Years)	—	—	—	—
Discount Rate 3%	5 yrs	15 yrs	33 yrs	21 yrs
Discount Rate 6%	5 yrs	15 yrs	50 yrs	21 yrs

Table 8. Break-even point (in years) when the TCO is equal to aluminum.

Material	Steel – 2 coats	Steel – 3 coats	Steel – Hot-dip galvanized	Steel – Hot-dip galvanized
Setting	Urban & Maritime	Urban & Maritime	Urban	Maritime
Discount Rate	24.3%	15.9%	6.1%	8.8%

Table 9. Discount rate required to make aluminum's TCO equal to steel.

Any discount rate below six percent makes aluminum a better choice than the steel option in all environments. Given the public financing of civil engineering structures like bridges, a lower discount rate is more likely. The use of a six percent discount rate is conservative, since investments of this nature are often required and government agencies do not generate revenue or profit.

A recent article [4] confirmed our result and highlighted the cost and technical advantages of an aluminum structure like one bridge in Arvida, Quebec. An aluminum structure would enabled the bridge to increase its load-bearing capacity, while reducing cost of ownership over the long term. Additionally, the article highlights the change in Canadian Standards Association bridge calculations for aluminum highway bridge structures, enabling both architects and engineers to develop designs using aluminum that respect the Association's rigorous norms.

Conclusion

Decision makers should no longer assume that steel is always the best option economically when investing in civil engineering structures. This analysis, using a pedestrian bridge project example, demonstrates that aluminum competes with steel when the Total Cost of Ownership is considered. The case for aluminum becomes even more apparent when the project is located in a highly-corrosive environment. Accordingly, while every project is unique, aluminum should have its place in the bidding process and be considered as an economical solution for civil engineering projects, since over its entire lifespan, an aluminum structure may prove to be the best option in terms of installation, maintenance, operation, and disposition costs.

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