galvanizers ASSOCIATION OF AUSTRALIA

THE CONCEPT OF LIFE CYCLE COSTING FOR THE CORROSION PROTECTION OF STEEL

Level 5, 124 Exhibition St., Melbourne, VIC, 3000 Australia

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Introduction

It is legend that Louis XV said, "Après moi, le déluge", or, in English, “After me, the flood”; meaning I don’t care what results from my actions, that’s for the people after me. The same can be said for those who ignore life cycle costing (LCC) of corrosion protection systems. A LCC analysis offers specifiers and asset owners a simple means of assessing the cost-effectiveness of alternative protective coatings for steelwork to be used in any new construction project over the design life of the structure.

Steel is one of the major products used in structures designed to last. From the mines we develop; the buildings in our cities; the bridges on our roads; to our homes and cars, steel is the material of choice. However, if left unprotected, steel will corrode over time. Therefore, if we want to increase the length of time our structures last, we must protect the steel from returning to its roots. The two most economic coatings usually considered for protecting steelwork from corrosion are:

- a paint system (primer plus one or more topcoats)
- hot dip galvanizing

In many cases, the cheaper initial cost coating system will require significant maintenance to retain aesthetic and corrosion resistance performance over the life of the project. Using the results of the LCC analysis, the estimated total lowest cost system can be identified and necessary maintenance programs developed to ensure future costs are minimised.

This guide reviews the theory of life cycle cost calculations and provides information on the practical use of an on-line LCC calculator (LCCC) developed by the GAA. It does not cover life cycle assessment, for example, life cycle inventory and environmental impacts. Details on life cycle assessments can be obtained from various sources, some of which are referenced here[1, 2, 3].

Project Design Life

Every owner will have a different requirement or philosophy with regard to the project design life of an asset. Often, the design life will be a requirement of Regulations, such as Australian Standards or the Building Codes. For some projects, where the item will be unserviceable once installed, the degree of corrosion protection will be the driver of the final decision. Other projects will be primarily concerned with aesthetics and maintenance programs will most likely be required to account for both ongoing aesthetic and corrosion prevention needs.

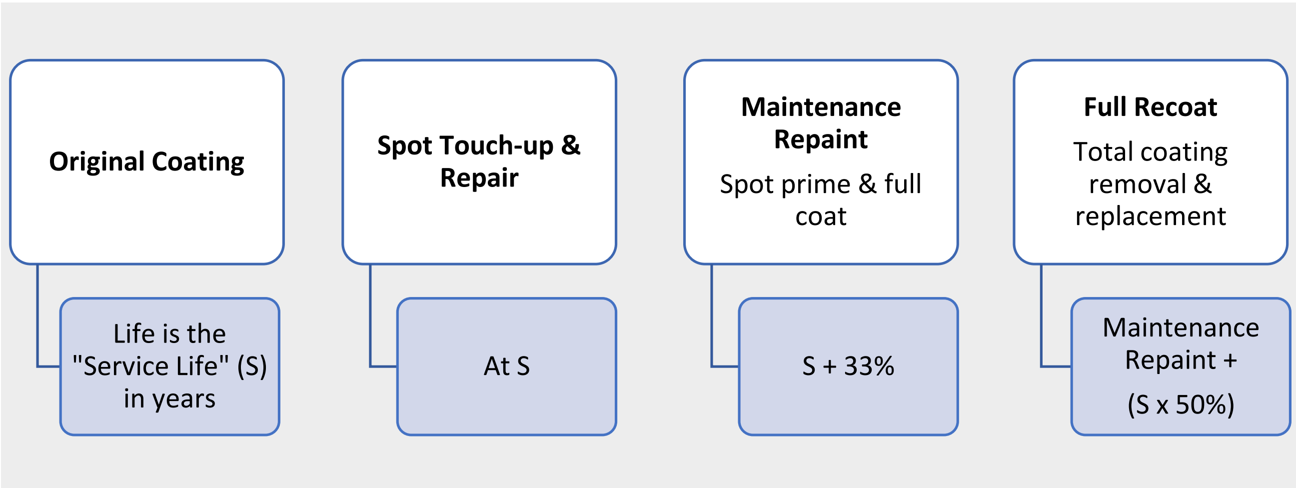
The original 1883 overland telegraph pole system was thought to have another 200 years of life left in the galvanizing when it was decommissioned in 1997.

Service Life

The service life typically refers to the practical life of the corrosion protection coating being used and this will not normally be the same as the project design life. The service life achieved will vary depending on the coating material, the structure, the environment and how the coating is applied. It is also important to recognise the assets' local environment may change over its design life and, where possible, this needs to be taken into account.

KTA Tator[4] assume the service life is reached when 5–10% coating breakdown and active rusting of the steel substrate is present (SSPC-Vis 2 Rust Grade 4). Of course, a 5–10% breakdown can occur in a specific area leading to a need for spot repair or over a wider part of the structure, leading to a need for full repaint.

Practical decisions on the level of maintenance required should be based on the results of a maintenance program, including regular assessment of the coating thickness, adhesion, substrate condition and the extent and distribution of any corrosion. A typical paint maintenance process is shown below.



For example, if the service life was 15 years, then the spot touch up and repair would be planned at year 15, the maintenance repaint planned at year 20, and full repaint required at year 28.

It is important to recognise this sequence does not always represent the most economical method of painting for each application. As with all planned maintenance programs, the individual circumstances of each structure and the environment (both macro- and micro-) will affect the outcome; hence the need for regular inspection and reporting. Section 8 of AS/NZS 2312.1[5] provides sound general advice on maintenance of paint coatings.

In many cases the life of hot dip galvanized steel is longer than the project design life, so maintenance is either not required or it is only spot touch-up. In cases where the design life is longer than the life of the galvanized steel, a similar process to that of a painted structure would be used to repair hot dip galvanized steel. Of course, if the design allows, the galvanized steel can be regalvanized to reduce expensive maintenance programmes.

The importance of coating thickness

The service life of a galvanized coating in any environment is proportional to its initial thickness (Table 1). Thinner zinc coatings such as electro-galvanizing (for example AllGal®), so-called 'cold galvanizing' (zinc rich paint) and continuous galvanizing (for example Galvaspan® or DuraGal®) are not normally as durable as batch hot dip galvanized coatings complying with AS/NZS 4680. In addition, continuously galvanized coatings are often cut and/or welded to fabricate the finished component. This introduces potential weaknesses in the corrosion protection system where the damaged coating has been repaired, often with a less durable paint system. Components galvanized to AS/NZS 4680 are normally fully fabricated prior to galvanizing, meaning no repair is required prior to installation and the total system is protected uniformly.

Table 1: Service Life Range in Various Environments (Years)[1]

System Description[2]	Coating Thickness (µm)[3]	C2 (low)	C3 (medium)	C4 (high)	C5 (very high)
HDG to AS/NZS 4680[3]	85	>100	40->100	20-40	10-20
HDG to AS/NZS 4680[3]	125	>100	60->100	30-60	15-30
Galvaspan® Z350[4]	20	29->100	10-29	5-10	2-5
DuraGal® AS/NZS 4792 ILG100	14	20->100	6-20	3-6	1-3
AllGal® AS4750 ZE50	7	10-70	3-10	1-3	0-1
Inorganic Zinc (IOZ) Rich Paint[5]	75	27	17	14	12
IOZ solvent borne (IZS1)[6]	75	25+	15-25	10-15	5-10
IOZ water borne (IZS3)[6]	125	25+	25+	15-25	10-15
Alkyd (ALK3)[6]	115	5-15	2-5	-	-
Polyurethane (PUR4)[6]	250	25+	15-25	10-15	5-10

Notes:

1. Micro-environments can affect the estimated durability of any coated steel and every effort should be made to identify the effects of any micro-environments in the design phase. The data for coating life range of galvanized systems is the calculated range from AS/NZS 2312.2 Table 6.1 and Table 6.2. The high number in each range is for the less corrosive end of the category and the low number is the more corrosive end of the category.
2. The systems described are not necessarily interchangeable and are shown only to provide examples of an increased coating thickness providing an increased life for the same corrosivity zone.
3. Coating thickness is in micrometres. For hot dip galvanized products to AS/NZS 4680, 85µm is the minimum average coating thickness for structural steel sections thicker than 6mm, while 125µm is the typical average coating thickness on heavy structural steel. Coating thickness varies according to the thickness of the steel and can be more or less depending on the section. Refer to AS/NZS 4680 for more information.
4. The coating thickness shown for Galvaspan is the minimum single-side thickness for Z350 product as nominated in the manufacturing standard (AS 1397).
5. The IOZ example here is as per KTA Tator Table 1A and interpolated for C4.
6. Data as per Table 6.3 from AS/NZS 2312.1 with C5 (very high marine). The on-line LCCC uses the NACE estimates of life and cost for inorganic zinc, alkyd and polyurethane, so these examples are shown for comparison purposes only.

Thicker paint coatings are normally specified in higher corrosivity zones to provide added barrier protection. Often these are achieved with multi-coat options. High-build paints can also provide for increased thicknesses. With all paint coatings, it is essential the edges and corners are appropriately prepared and coated – often with an additional stripe coat to 'break' the edge or the base steel is chamfered to stop the paint bleeding away from the edges and corners or both, especially when long term corrosion protection is required (for more information see Clause 7.10.2 of AS/NZS 2312.1).

Coating Reliability

While hot dip galvanized coatings are factory-applied under controlled conditions, painting is often a manual process that is labour intensive and dependent on operator skills. Nevertheless, paint coatings offer the flexibility of application on-site as well as in a painting shop. In addition, a variety of paint systems are available from a simple 'wire brush and primer' to exotic paint systems applied over blast-cleaned surfaces. However, this flexibility comes at a price. Paint application is generally restricted to external surfaces and uniformity becomes difficult with complex fabrications. Paint coatings are affected by temperature, humidity and condensation during application and are more easily damaged during transport and erection than galvanized coatings.

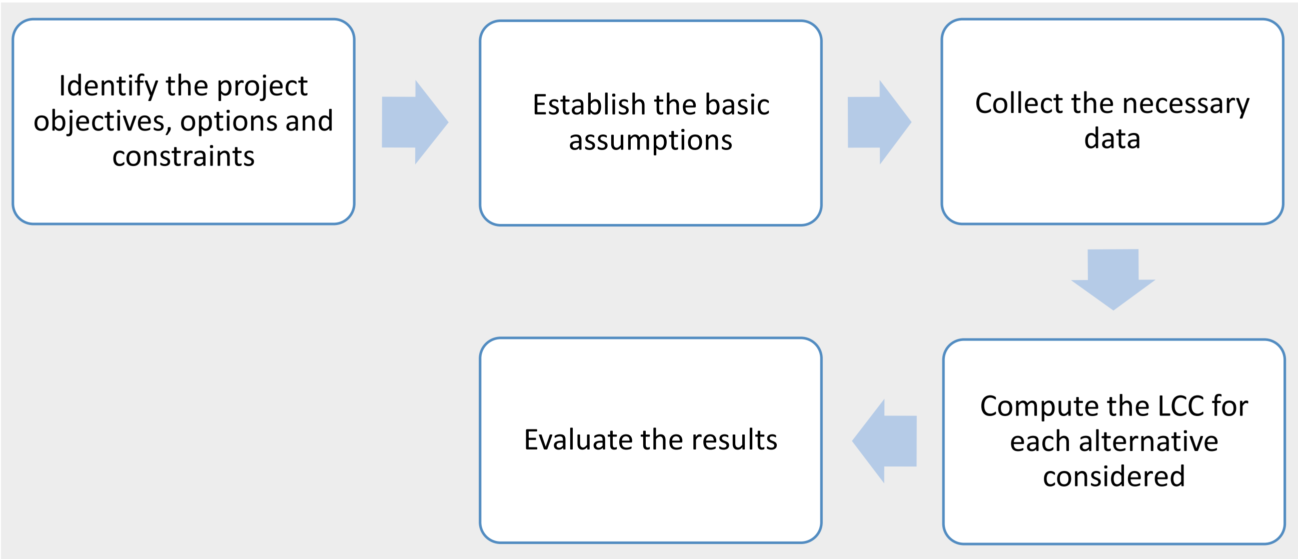
Salt Spray Tests – Performance Claims

The salt spray test (SST) was first developed in the 1930's to prove the quality of a coating, rather than the performance of the coating. The most common of the SST is ASTM B117. For some paints the SST provides a reasonable indication of performance but for metallic coatings including zinc rich paints, the SST results seldom correlate to real life performance in natural environments. The SST cannot be used to assess the life of a coating because it accelerates the wrong failure mechanism. Without a proper wet/dry cycle, the zinc coating cannot form patina layers. The absence of a patina layer allows constant attack of the zinc metal and gives a very low prediction of the zinc coating lifetime.

Similarly, when painted steel is evaluated for corrosion protection only using the SST, there is no exposure to ultraviolet light, a common cause of breakdown of organic paints. This is a serious omission, since the main failure mechanism that causes painted steel to deteriorate is not included as a condition in the SST.

Procedure for Performing a LCC Calculation[7]

Shown below are the five basic steps in performing a LCC calculation.



Project Objectives, Options, and Constraints

By way of example, a masonry structure will typically include openings that require reinforcing. An often-used solution is steel lintels, which have a requirement to comply with the National Construction Code, AS 3700 or AS/NZS 4773 (design) and AS 2699.3 (durability) with an expected design life of 50 years (**the objective**). The lintels could be galvanized, painted or manufactured from stainless steel (**the options**). The lintels typically have limited access for maintenance and need to be able to carry a certain load (**the constraints**) once the structure is in service.

Basic Assumptions

These are the assumptions to be applied across each potential solution, such as the selection of the **interest rate**, the **general rate of inflation**, the **project design life** and the level of **precision** needed to study the alternative solutions for the project – in other words, the assumptions common to the project, irrespective of the coating solution chosen.

The **interest (or discount) rate** should reflect the asset owner's time value of money. Selection of the interest rate will sometimes reflect the rate of return on alternative investment opportunities or, if the asset owner is a government body, may reflect the mandated requirement.

The **general rate of inflation** is normally calculated using the Consumer Price Index (CPI).

The **project design life** should be the same for each calculation for consistency of comparison (the GAA LCCC assumes this), and the life is determined from the customer or mandated requirements. If major design changes can be foreseen that will cause changes to the existing corrosion protection, then the chosen design life should not extend past these changes.

The amount of **precision** and detail included in the calculations should be commensurate with the risk and value of the project. A less comprehensive analysis is usually sufficient on a 'first-off' basis. The GAA LCCC provides a starting point for further analysis, with average costing for a wide range of paint solutions, across a number of project classifications. The LCCC also allows the end user to vary the potential solutions, galvanizing cost and project design life to determine the **sensitivity** of the project costs.

Collecting the necessary data

Sometimes during the course of a construction project, decisions on steel protection become secondary to other engineering issues. It can be tempting to take a minimum cost approach and deal with any later corrosion problems as a maintenance expense as they arise.

However, the true cost of protecting steelwork from corrosion requires a whole of life approach. Account needs to be taken, not only of the initial coating costs, but also of reasonably predictable future costs essential to maintaining both the steel and coating integrity over the life of the project. A lifetime approach is important because the cost of maintaining protective coatings will invariably be much higher than the initial coating cost.

Initial Costs

The initial cost of any coating is normally defined as the total cost required to bring the system to a point of functional readiness. First costs include materials and labour, as well as transport, inspection, repair of any damage during transport or erection and late delivery penalties.

Hot dip galvanized coatings are always quoted as a dollar cost per tonne of steel ($/t), whereas paint coatings are usually costed by surface area in dollars per square metre ($\$/m^2$). Consequently, the cost of hot dip galvanizing is not directly proportional to the surface being treated, but rather to the total weight of steel involved.

Lifetime and Future Maintenance Costs

These will be determined by the number of times the coating requires maintenance during the structure's life and any contingent costs incurred due to replacement of corroded components or loss of use or production from the structure.

Maintenance of a coating will usually include costs associated with the rehabilitation or repair of a coating system and should take into account the following items:

- mobilizing plant and labour
- access to the structure (scaffolding)
- materials (abrasives, paint, etc.)
- provision of services (power, compressed air, transport, accommodation)
- environmental and OH&S management (hazard containment)
- use of or lost production from the structure being maintained

Computing the LCC

It is a fact costs prevailing today will not be the same in the future. Maintenance costs will be impacted by inflation, which a LCC model accommodates by expressing future costs in terms of their **Net Future Value (NFV)** and **Net Present Value (NPV)** [4,5,7,8].

NFV is the current cost with inflation included, in other words, how much something will cost in inflated dollars *(i = inflation)* in the year *(n)* in which it occurs

$$NFV = Current\ Cost\ \times (1 + i)^n$$

NPV involves the use of interest rates, inflation rates and taxation impacts, to test the benefit of spending less now on coatings (minimum first cost approach) against the cost of future maintenance.

The present value ($NPVLCC$) of a coating will simply be the sum of the initial coating cost ($NPVIC$) and the repair or rehabilitation cost ($NPVR$), using the appropriate interest rate.

$$NPVLCC = NPVIC + NPVR$$

In addition to inflation, it must be kept in mind that increasingly stringent environmental and occupational health and safety requirements will influence the future cost of materials, energy and labour, as well as the cost of containment and residue disposal.

The initial costs are assumed to occur in year zero and require no interest rate, while repair or rehabilitation costs are assumed to occur at a single point in time in the future *(n = number of years)* and can be discounted back to the present by the use of the interest or discount rate *(i)*.

$$NPV = NFV \left[\frac{1}{(1 + i)^n}\right]$$

Of course, there may be multiple repair points for a coating system to reach the estimated project life and these need to be taken into account.

A common method to assess long term project costs used by engineers is the **Average Equivalent Annual Cost (*AEAC*)**, which takes the total NPV of a project and distributes the cost equally over the structure's life *(n)* with a standard interest rate *(i).*

$$AEAC = NPV \left(\frac{i(1 + i)^n}{(1 + i)^n - 1}\right)$$

The NPV, NFV and AEAC are calculated in the GAA Life Cycle Cost Calculator by the user providing the inflation rate and the interest rate for each project.

It is important to recognise the initial coating would normally be incorporated in the capital investment decision in Australia, while repairs and maintenance (for example painting) are usually tax deductible. This may affect the decision on the coating selected 'up front' and professional financial advice should always be sought when considering life cycle costing of a project.

The above pictures show early failure of the paint system in a C2/C3 environment well before any red rust on the galvanized components. The owners of these assets will need early intervention to extend the asset life to their original expectations.

Evaluating the results using the GAA Life Cycle Cost Calculator

The GAA Life Cycle Cost Calculator (LCCC), http://lccc.gaa.com.au/, provides a practical guide to the basics of life cycle costing, including the overall durability of each system, what the total installed cost might be and the ongoing maintenance costs of each system. The data is based on a paper titled "*Expected Service Life and Cost Consideration for Maintenance and New Construction Protective Coating*"[4] presented to the 2014 NACE Conference and a similar calculator developed by the American Galvanizers Association; modified by the GAA to suit Australian and New Zealand terminology.

The costs in the calculator are not intended to be used for detailed project cost estimating, however the calculator is intended to provide a comparison between the initial cost and lifetime costs of various systems. Care should be taken with the costs of each nominated system (whether galvanized, painted or thermal spray) as each job will have specific customer requirements that will affect the total costs such as lead time, location of the fabricator and the final site, transport, inspection and the mark-up applied by the value chain. In addition, the size of the job and the level of competition within any market often play an important part in the costs, both initially and during maintenance periods.

For the purpose of this paper we have compared the coating cost and performance on a simple steel structure with steel thickness more than 6mm thick, for three paint coating systems against a standard AS/NZS 4680 (85µm coating thickness) system as follows:

- One coat of inorganic zinc silicate at 75µm DFT in a C3 environment (IZS1)
- Two coats of alkyd, total DFT 100µm in a C2 environment (ALK3)
- Three coats of a polyurethane system, total DFT 250 µm in a C3 environment (PUR4)

Example project details:

This project was deliberately chosen so that the reader can see an example where systems with a similar first cost deliver significant lifetime cost variations through differing maintenance requirements.

- Project size: 100 tonnes
- Target design life: 50 years
- Structure type: Simple <15 m high with a typical mix of structural shapes & sizes (25 m^2/tonne)
- Service environment: C2 (low) for alkyd and C3 (medium) for inorganic zinc and polyurethane
- Inflation: 4%
- Interest Rate: 7%
- Paint systems:
    - **AS/NZS 2312.1 IZS1** – 75 µm coating thickness, 1-coat IOZ (inorganic zinc) system, made up of a Sa 2½ class blast (conventional with recyclable abrasives), shop painted, and a service life 20 years. Initial applied cost of \$30/m^2.
    - **AS/NZS 2312.1 PUR4** – 250 µm coating thickness, 3-coat polyurethane system made up of a Sa 2½ class blast (conventional with recyclable abrasives), a zinc rich epoxy primer, epoxy intermediate and polyurethane top coat, all shop painted, and a service life 20 years. Initial applied cost of \$55/m^2.
    - **AS/NZS 2312.1 ALK3** – 100µm coating thickness, 2-coat alkyd system made up of a Sa 3 class blast (conventional with recycled abrasives), an alkyd primer and alkyd (gloss) top coat, all shop painted, and a service life of 10 years. Initial applied cost of \$23.60/m^2.
- Hot dip galvanizing:
    - **AS/NZS 4680 HDG600** – 85µm minimum average coating thickness, and a service life of more than 50 years (as described in AS/NZS 2312.2 Table 6.1 and Table 6.2). Initial applied cost: \$600/tonne (\$24/m^2).

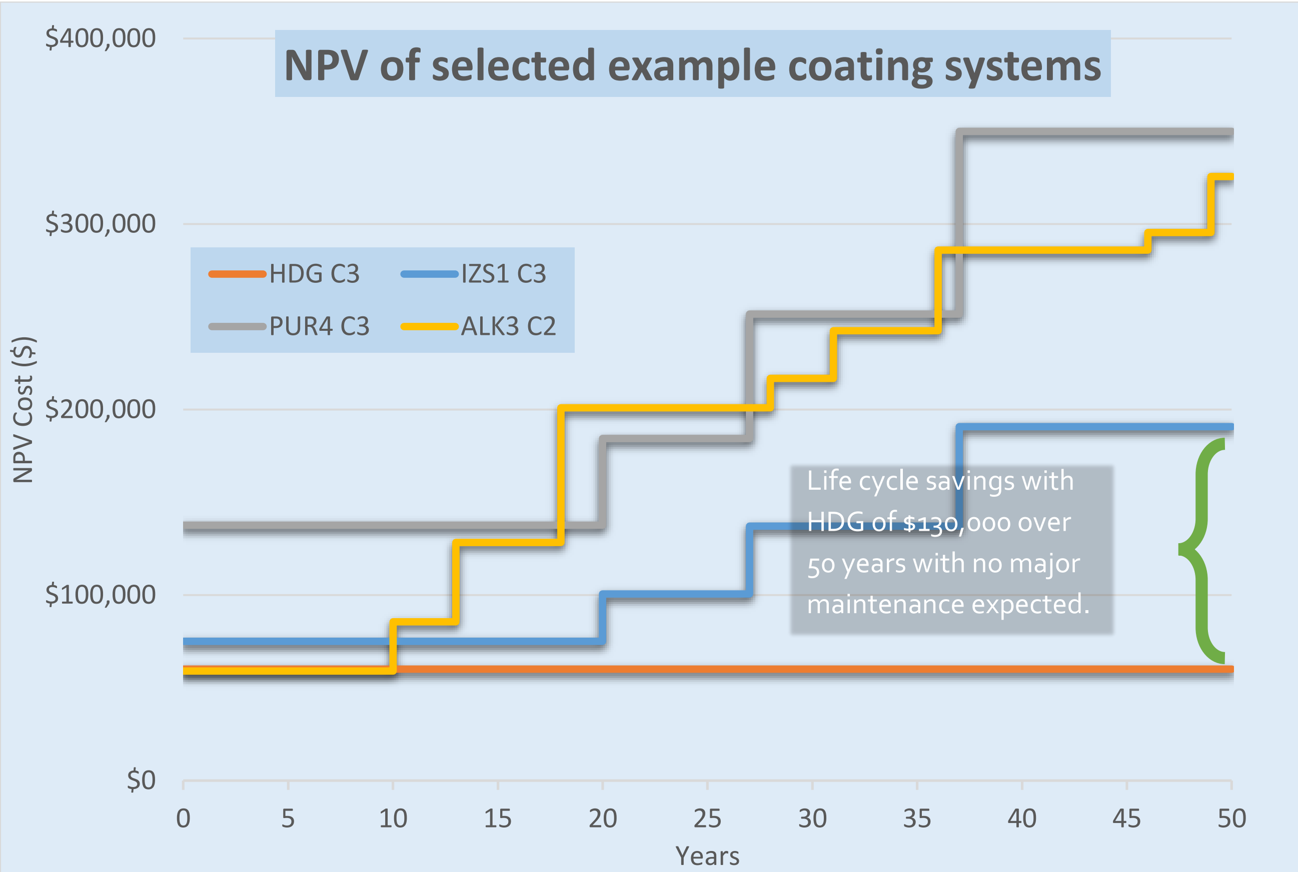
Note: The hot dip galvanizing and paint system costs in this example are not represented by the GAA to be the true cost of any particular example, but do represent a typical cost for a range of applications. Your GAA member galvanizer will supply a quote for hot dip galvanized pricing based on the individual characteristics of your application, on request.

Summary Cost Comparison

Coating System	Initial Cost		Net Present Value (Life Cycle Cost)		AEAC	HDG Lifetime Savings Ratio
	$ per m²	$ Total	$ per m²	$ Total	$ per m²	
AS/NZS 4680 HDG600	$24.00	$60,000	$24.00	$60,000	$1.74	---
AS/NZS 2312.1 IZS1	$30.00	$75,000	$76.28	$190,705	$5.53	3.2
AS/NZS 2312.1 PUR4	$55.00	$137,500	$139.85	$349,629	$10.13	5.8
AS/NZS 2312.1 ALK3	$23.60	$59,000	$130.24	$325,597	$9.44	5.4

For this project, the life cycle costing shows the **lifetime savings using HDG are more than 3 times** that of the single coat inorganic zinc silicate system in a C3 environment, even though the cost of each system was initially similar. For an internal application in a C2 environment, **HDG offers nearly 6 times the lifetime savings** compared to a simple 2-coat alkyd system often used in warehouse designs.

The following graph shows how the maintenance cycle affects the overall cost of a system to an asset owner, and the initial cost is often not the driver of the total cost.



Other Information

Structural steel weights and surface areas can be obtained from the relevant Australian and/or New Zealand Standards, from the GAA, or from OneSteel manuals available on-line.

Structure types and sizes are allowed for in the LCCC. Hot dip galvanizing baths are limited in size and some structures may need to be double-end dipped or designed to be joined with bolted connections to allow long members to be galvanized which will affect pricing in some designs, so average pricing should not be used in these cases. For more information, speak to the GAA or any GAA member galvanizer.

Summary

Life cycle costing is a useful method for determining the most cost effective coating for corrosion protection of steel over the life a project. It provides designers with an easy to use system for comparing various alternative solutions. The GAA Life Cycle Cost Calculator further simplifies the process by providing typical costs for a range of common paint alternatives and allowing them to be compared to the cost of a hot dip galvanized structural steel member. In most cases, where long term corrosion protection is required, hot dip galvanizing provides the most cost effective coating solution.

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8. International Zinc Association, *Life-cycle costing of protective coatings for steel,* (undated), sourced from www.galvanizingasia.com, accessed 15 January 2013.

Detailed cost comparison data for the chart and table of paint systems

	Today's Cost $ per m²	Net Future Value $ per m²	Net Present Value $ per m²
HDG to AS/NZS 4680 HDG600 – 85µm minimum average thickness, located in a C2 or C3 environment			
Initial cost	24.00	24.00	24.00
Total cost	**24.00**	**24.00**	**24.00**
Paint system – IZS1 – 1 coat inorganic zinc silicate, 75µm total DFT, located in a C3 environment			
Initial cost	30.00	30.00	30.00
Touch-up – Year 20	18.00	39.44	10.19
Maintenance repaint – Year 27	31.50	90.83	14.62
Full repaint – Year 37	61.50	262.49	21.47
Total cost	**141.00**	**422.75**	**76.28**
Paint system – PUR4 – 3 coat polyurethane system, 250µm total DFT, located in a C3 environment			
Initial cost	55.00	55.00	55.00
Touch-up – Year 20	33.00	72.31	18.69
Maintenance repaint – Year 27	57.75	166.51	26.80
Full repaint – Year 37	112.75	481.23	39.37
Total cost	**258.50**	**775.05**	**139.85**
Paint system – ALK3 – 2 coat alkyd system, 100µm total DFT , located in a C2 environment			
Initial cost	23.60	23.60	23.60
Touch-up – Year 10	14.16	20.96	10.66
Maintenance repaint – Year 13	24.78	41.26	17.12
Full repaint – Year 18	48.38	98.01	29.00
Touch-up – Year 28	14.16	42.46	6.39
Maintenance repaint – Year 31	24.78	83.59	10.26
Full repaint – Year 36	48.38	198.55	17.38
Touch-up – Year 46	14.16	86.02	3.83
Maintenance repaint – Year 49	48.38	330.60	12.01
Total cost	**260.78**	**925.04**	**130.24**