The embodied energy analysis also results in a biased view of a project's sustainability metrics. The analysis performed in this paper is concerned only with the total volume of materials, but further analysis needs to take into account the energy costs of transporting materials to site. The embodied energy results as presented here also neglect end-of-life recycling of material, which a full life cycle analysis would capture. Regardless of these shortcomings, embodied energy analysis will never be able to take into consideration societal factors like employing underrepresented groups or enhancing public space. It is instead a purely quantitative indicator of sustainable performance.

CONCLUSION

The Envision rating system has a different focus from what researchers in sustainable infrastructure are accustomed to seeing. Instead of a quantifiable analysis resulting in a defined amount of embodied energy or carbon, Envision evaluates a project much more subjectively. This holistic approach weighs societal factors more heavily than any energy study performed to date. The drawback to this is that a new paradigm such as Envision can only begin the conversation for the industry – the onus of work to develop and refine the system requires the collective effort of many. Owners and clients must push for Envision rather than LEED on their infrastructure projects in order for the system to progress. It is especially important that engineers and architects are brought on early in the process to fully implement integrated, holistic solutions in the final design. The ultimate goal for all is a system with balanced, sensible metrics that produce truly sustainable infrastructure projects.

REFERENCES

Collings, D. (2006). An Environmental Comparison of Bridge Forms. *Proceedings of the Institute of Civil Engineers*, 163-168.

Hammond, G. P., & Jones, C. I. (2008). Embodied energy and carbon in construction materials. *Proceedings of the Institute of Civil Engineers*, 87-98.

Long, A. E., Basheer, P., Taylor, S., Rankin, B., & Kirkpatrick, J. (2008). Sustainable Bridge Construction Through Innovative Advances. *Proceedings of the Institute of Civil Engineers*, 183-188.

Martin, A. J. (2003). Aspects of Concrete Bridges in Sustainable Development. *Concrete Bridges in Sustainable Development.* Dundee, Scotland.

Wong, A. (2011). *Embodied Carbon Life-Cycle Assessment of Bridges: A Case Study of a Sea Crossing in Hong Kong.* Hong Kong.

Zhang, C. (2010). Delivering Sustainable Bridges to Help Tackle Climate Change. *Proceedings of the Institute of Civil Engineers*, 89-95.

The Gerald Desmond Bridge Replacement Envision™: Using Key Project Innovations to Understand the Envision™ Framework

Josh Mattheis[1] P.E. ENV SP, Mike Iswalt[2] AICP PTP, Josue Enriquez[3] ENV SP and Joshua Bird[4] ENV SP

[1] M.S.C.E, B.S.C.E; Arup; 12777 West Jefferson Blvd Building D Los Angeles, CA 90066; PH (310) 578-4502; email: josh.mattheis@arup.com
[2]M.S.C.E, M.C.R.P; Arup; 560 Mission Street, Suite 700, San Francisco, CA 94105; PH (415) 946-0748; email: michael.iswalt@arup.com
[3] M.S.C.E, B.S.C.E; Arup; 12777 West Jefferson Blvd Building D Los Angeles, CA 90066; PH (310) 578-4421; email: josue.enriquez@arup.com
[4] MEng Civil and Structural Engineering; Arup; 12777 West Jefferson Blvd Building D Los Angeles, CA 90066; PH (310) 578-4559; email: joshua.bird@arup.com

ABSTRACT

The purpose of this paper is to use the Envision™ framework to evaluate a portion of the Gerald Desmond Bridge Replacement Project (GDBRP), located in the Port of Long Beach (POLB), in order to test the applicability of Envision™ framework to similar projects around the world. Evaluation will focus on a portion of the western approach to the main span, proposed in the project reference documents as an elevated horse-shoe ramp but modified through value engineering to an undercrossing, using roadway geometry referred to as the Port Access Undercrossing (PAUC). Acknowledging that many infrastructure owners already have their own sustainability guidelines, this paper also examines synergies between Envision™ and the Port of Long Beach's own sustainability framework, the Green Port Policy (GPP).

The Envision™ analysis confirms benefits across several different criteria introduced to the GDBRP by the application of the PAUC alternative. Comparison of the Envision™ analysis results to POLB objectives indicate that the Envision™ framework is well adapted to work within objectives of the POLB's GPP by providing tools to evaluate a wider range of assets.

INTRODUCTION

Sustainability is a key component of any large infrastructure project, but design builders often struggle to grasp what a sustainable project entails in solid terms. Envision™ provides the framework within which designers and contractors can work to design and construct a truly sustainable project, providing a holistic approach to sustainability that is all-too-often poorly applied on infrastructure projects.

Located in the Port of Long Beach, California, GDBRP presents an ideal context to explore the potential of Envision™ when assessing the sustainability of infrastructure projects for several reasons:

- POLB is the second busiest container port in the United States, after the neighboring Port of Los Angeles, making the context relevant for other large Port projects.
- GDBRP is critical to the continued growth of the Port of Long Beach, establishing the bridge as a critical economic link.
- The contract procurement model is design and build, coherent with developing world-wide trends toward design and build.

Thus, GDBRP is relevant in terms of its physical context, economic significance and contract procurement type, all increasingly common aspects of large capital improvement projects around the world.

Envision™ Structure

Envision™ is a sustainability rating system establishing a holistic framework for evaluating and rating infrastructure projects against the needs and values of the community, not only during construction, but during the project's design life. It is intended to be applied to and adopted by the infrastructure industry, similar to how LEED has become an industry standard for green building projects.

The Envision™ system is comprised of four stages as noted in Figure 1. The first stage is aimed towards the conceptual phase of a project, while the second focuses on the detailed design and construction phases. Stages 3 and 4 are still under development by the Institute for Sustainable Infrastructure (ISI) and Zofnass Program for Sustainable Infrastructure.

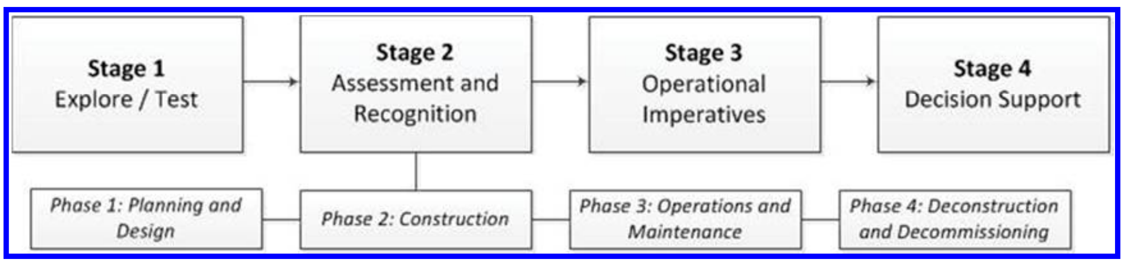


Figure 1. Structure of Envision™ Rating System

In order to evaluate a project, sixty credits are proposed, organized into five categories and fourteen subcategories:

- Quality of Life: Purpose, Community, Wellbeing
- Leadership: Collaboration, Management, Planning
- Resource Allocation: Materials, Energy, Water

- Natural Work: Silting, Land and water, Biodiversity
- Climate and Risk: Emissions, Resilience

These categories are evaluated in Stage 1 and again in Stage 2, but with more detail. The Stage 1 evaluation is a high level assessment intended to rapidly compare project alternatives, facilitated with a checklist-style tool developed by ISI. During Stage 2, a more in-depth assessment is performed with justifications for each category, ultimately to be submitted to ISI for their scoring. Scores are proclaimed as either:

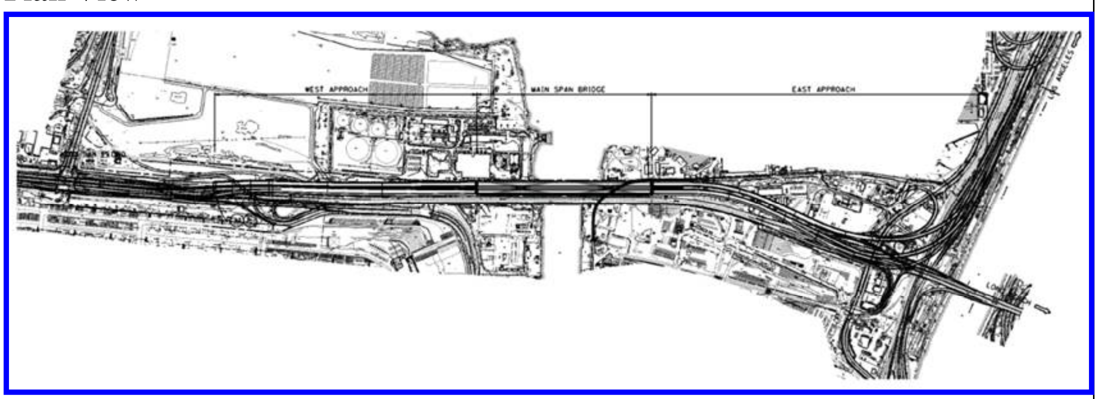
(1) Improved (2) Enhanced (3) Superior (4) Conserving (5) Restorative

This allows the project to be rated in a way which is quantifiable and measureable, rather than purely qualitative.

Gerald Desmond Bridge Replacement Project Background

As depicted in Figure 2, the Gerald Desmond Bridge Replacement Project features a network of approximately 6,000 feet of box girder approach structures leading up to a 2,000 foot long cable-stayed main span bridge with a 100-year design life. The new bridge is located immediately adjacent to the functionally deficient existing bridge, which will remain in service until the replacement bridge is opened. When finished, the replacement bridge will improve traffic flows across the bridge and increase vertical clearance to the shipping lane below, permitting the increasingly common Post-Panamax cargo ships to pass. Total project cost is currently assessed at approximately 1.2 billion dollars.

Plan View



Elevation View

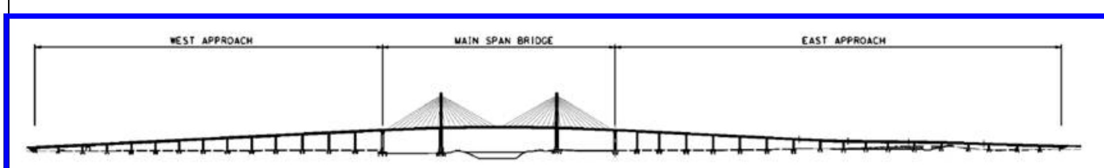


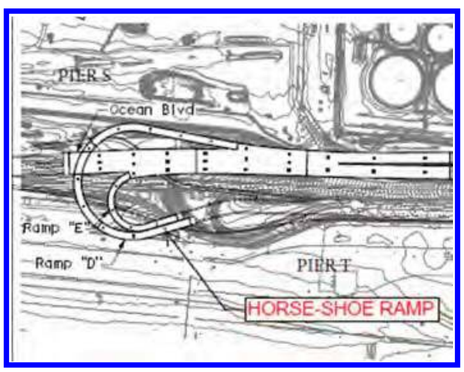
Figure 2. Gerald Desmond Replacement Project plan and elevation view.

HORSESHOE vs. PAUC

As shown in Figure 3, the tender reference design (the reference design) features a vertically grade-separated "horseshoe" bridge structure at the western approach to the GDBRP providing access from the new westbound bridge to Pier T Avenue and from Pier T Avenue to the new eastbound bridge. At-grade ramp connections were provided between Pier T Avenue and Ocean Boulevard. The horseshoe ramps allow full access between Pier T Avenue and Ocean Boulevard.

The SFI Joint Venture (SFIJV) proposed to replace the horseshoe ramps in the reference design with two protected PAUC U-turn lanes east of State Route 47 (Terminal Island Freeway). Vehicles traveling westbound Ocean Boulevard towards the main Totals Terminal International (TTI) entrance would then use one of the dedicated free flow U-turn lanes to cross under Interstate-710 instead of the horseshoe ramps included in the reference design. Vehicles leaving the main TTI exit and travelling east towards Ocean Boulevard would cross under Interstate-710 via a newly constructed local access road and use the second dedicated free-flow U-turn lane to access eastbound Interstate-710.

Horse-Shoe Ramp



PAUC

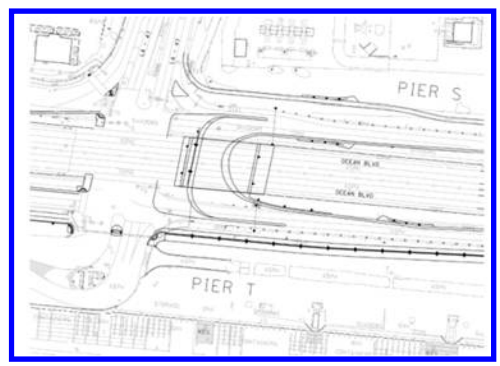


Figure 3. Horse-Shoe Ramp vs. PAUC Design.

At the westbound Ocean Boulevard / State Route 47 intersection, the left-turn lane is eliminated and replaced with a shared left/through lane. The eastbound travel lanes at the eastbound Ocean Boulevard / State Route 47 intersection are realigned slightly to the south to line up with the receiving lanes on the other side of the intersection. No changes to the lane configuration are proposed. These changes do not adversely affect the Level of Service (LOS) compared to the reference design.

The application of this roadway geometry on a California Department of Transportation (Caltrans) roadway network is unique in context, but the change was accepted by the Port of Long Beach based on the many advantages it brings across several categories. As well as being innovative, the PAUC provides an ideal context for comparison with the reference design using the Envision™ framework.

METHODOLOGY

Envision™ analysis is carried out within the confines of a Stage One analysis, augmented with detailed fact-finding and assessments where possible. This approach reflects the actual status of the project at the time of this analysis, being that the detailed design is only partially complete. A full Stage Two analysis is not yet feasible, but enough information exists to exceed what would typically be a high level Stage One analysis.

As depicted in Figure 4, a high level assessment of the entire GDBRP is performed using the Envision™ Self-Assessment checklist first with the reference design layout, and again with the PAUC. In this way credits relevant to the comparison are identified by their divergent values between the reference design and the PAUC design. These credits are isolated, and examined with a more detailed collection of information. An accurate picture of the differences between the two options within the Envision™ framework is thus developed without dwelling on the aspects which are not impacted by the introduction of the PAUC.

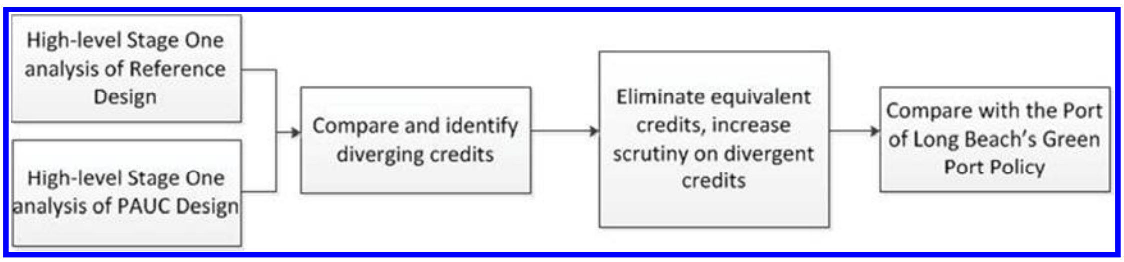


Figure 4. Analysis of methodology.

Following the above exercise, use of the Envision™ framework in conjunction with the Port of Long Beach's Green Port Policy is considered as a discussion.

Identification of Stakeholders

The Envision™ framework places heavy emphasis on quality of life, community, well-being, collaboration, and planning, all of which require an accurate assessment of the local stakeholders. There are numerous stakeholders project-wide, but in the context of this assessment, a shortlist of stakeholders directly impacted by the Horseshoe ramp / PAUC alternative is used as listed below:

- Port of Long Beach
- Port of Los Angeles
- City of Long Beach

- Caltrans
- Totals Terminal International (TTI)
- Commuters from San Pedro south bay to Long Beach

Envision™ Assessment of PAUC vs. Horse Shoe

Figure 5 summarizes the results from the Envision™ Self-Assessment Checklist after performing a high level Stage-One analysis for both the PAUC and Horse Shoe reference design. The "Percent Credits Achievable" chart highlights the percentage of credits, listed in the Envision™ checklist, applicable for each sustainability category. Conversely, the "Percent Credits Not Achievable" chart shows the percentage of credits that cannot be achieved. The self-assessment checklist provides a quick and quantifiable comparison between the PAUC and Horse-Shoe reference design, in terms of sustainability, as defined by Envision™. Although the percentages shown in the table do not reflect a definite level of sustainability performance, it does hint at which alternative will perform higher in a Stage-Two Envision™ analysis.

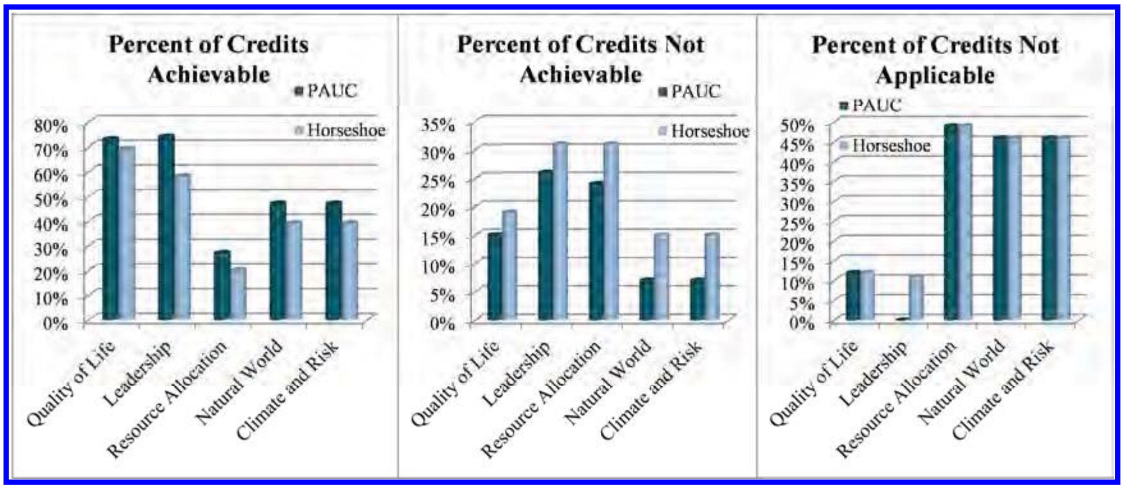


Figure 5. Envision™ Self-Assessment Checklist Results.

The Envision™ self-assessment checklist indicates a preferential trend for the PAUC in all five sustainability categories.

Compared to the Horse-Shoe reference design, the PAUC improves the community's quality of life by reducing the amount of bridge construction and associated noise and vibrations. However, we note that when evaluating credit QL 2.2 Minimize Noise and Vibration, both the reference design and the PAUC reflected the same "Yes" assessment even though the PAUC presents clear advantages in terms of this criterion. This underlines a risk of a rapidly performed Stage 1 analysis.

The largest difference between the PAUC and the reference design is in the Leadership category. By proposing the PAUC option, the project team championed a non-standard solution never before adopted in the state of California, providing benefits to several stakeholders. Envision™ acknowledges the leadership required to make new ideas such as the PAUC a reality through credits such as LD3.2 - Address Conflicting Regulations and Policies. This pursuit accounts for the 16% difference in the Leadership category between the PAUC and the reference design.

Modest improvements are also noticeable for the Natural World and Climate and Risk categories with a difference of 8%. The variance is attributed to the following factors:

- The PAUC avoids excavating into a benzene plume (NW1.4 Avoid Adverse Geology).
- The PAUC reduces the percentage of Low Solar Reflectance Index by limiting the amount of asphalt required (CR2.5 Manage Heat Island Effects).

The removal of the Horseshoe ramps significantly reduces the net embodied energy (RA1.1 Reduce Net Embodied Energy) of the project which accounts for the 7% difference under the Resource Allocation category.

Table 1. Embodied Energy and Carbon Conversion Values

Item	Concrete	Steel
Embodied Energy [MJ/kg]**:**	0.950	24.4
Embodied Carbon [kgCO_2/kg]**:**	0.130	1.77

Using the rates described in Table 1, Table 2 summarizes the Net Embodied Energy savings obtained by replacing the Horse-Shoe ramps with the PAUC design, using approximate steel reinforcement quantities per cubic meter of concrete as identified by Caltrans (2005).

Table 2. Embodied Energy and Carbon

Item	Horseshoe Ramps	PAUC	Savings
Embodied Energy [MJ x 10^6]**:**	80.0	11.2	**68.8**
Embodied Carbon [kgCO_2 x 10^6]**:**	8.06	1.07	**6.99**

According to the Environmental Protection Agency (EPA), the embodied energy saved by selecting the PAUC over the Horseshoe ramps is the equivalent of 1,483,000 gallons of gasoline consumed. Similarly, the combined savings of carbon dioxide is the equivalent of 780,000 gallons of gasoline consumed (EPA, 2014).

Synergy with POLB Green Port Policy

The POLB has long been considered a leader in sustainable port practices ("Greening of California 2006" Award) and as such has implemented a Green Port Policy (GPP). While Envision™ is an assessment framework rather than a policy, significant parallels can be drawn between it and the Port of Long Beach GPP.

In its GPP, the POLB has developed a 'decision-making framework' (Port of Long Beach, 2014) to mitigate the negative impacts associated with port operations. Evolving from the POLB previous 'Healthy Harbors Program' the GPP was adopted in 2005 with fundamental goals associated with 'Air, Water, Wildlife, Soil/Sediment, Sustainability, and Community Engagement'. While Envision™ is an excellent tool, general enough to be applicable to the full spectrum of infrastructure projects, the GPP is clearly and unsurprisingly, specific to the operations of a port.

Though metrics exist within the GPP, some principles such as water and wildlife is less measurable. In these categories, pairing the GPP with Envision™ could prove beneficial. There is scope to further investigate the correlation between Envision™ and GPP which could be mutually beneficial to stakeholders, adding value to the GPP and promoting the use of Envision™ on major infrastructure projects. Both documents should be viewed as complimenting each other, and playing different roles, to be applied to a project in tandem, rather than as an either-or.

Whilst there are targets within the GPP for attaining LEED accreditation for new buildings, there is currently no similar target for the upgrades to infrastructure. Perhaps that is because until now, there was no infrastructure equivalent to LEED. Envision™ could compliment the GPP in a manner similar to how LEED has for its building projects.

CONCLUSION

The Envision™ framework provided a versatile and effective toolset to evaluate GDBRP reference design and PAUC scenarios, and ultimately confirmed that the PAUC is the preferable configuration. The organization of target credits into categories and category sub-sets is an effective way to rationalize a large and variable set of data. By providing ready-made tools such as the Envision™ Self-Assessment checklist, ISI has enabled teams such as SFIJV and the Port of Long Beach to roll out an efficient and consistent basis of comparison.

The disadvantages of the Envision™ framework are related to its universal nature, particularly in the Stage One analysis where this study is largely based. In order to be applicable to a wide range of situations, credit evaluations tend to be open to interpretation to the point where some potentially key project aspects may not be accurately reflected in the evaluation. As an example, in evaluating credit QL 2.2