Measuring the Milton-Madison Bridge Aesthetic Preferences of Multiple Subgroups Simultaneously Through the Use of Structured Public Involvement and the Casewise Visual Evaluation Process

Theodore H. Grossardt, University of Kentucky
John B. Ripy, University of Kentucky
Keiron Bailey, University of Arizona

Available at: https://works.bepress.com/ted_grossardt/60/
Measuring the Milton-Madison Bridge Aesthetic Preferences of Multiple Subgroups Simultaneously Through the Use of Structured Public Involvement and the Casewise Visual Evaluation Process

Dr. Ted Grossardt, Research Program Manager and
Mr. John Ripy, GIS / Visualization Manager
University of Kentucky Transportation Research Center
And

Dr. Keiron Bailey, Associate Professor
Department of Geography and Regional Development
University of Arizona

Review and Comments by
John Carr and Samantha Wright, Wilbur Smith and Associates
Lexington, KY
And

Aaron Stover, Michael Baker Jr. Inc.
Louisville, KY
Table of Contents

1. Project Properties That Impact Public Involvement ................................. - 4 -
   1.1. Time Scale of Project ........................................................................ - 4 -
   1.2. Spatial Extent of Area Impacted By Project .................................. - 4 -
   1.3. Breadth and Depth of Public Impact ............................................... - 5 -
   1.4. Problem Complexity and Proliferation of Solutions ..................... - 6 -
   1.5. The Type of Public Involvement in the Design Process ............... - 6 -

2. Large Scale Bridge Design ....................................................................... - 8 -
   2.1 Typical Constraints On the Bridge Design: The “Design Envelope”  - 8 -
   2.2 Process Guidance from Bridge Designers ...................................... - 11 -
   2.3 Approaches to Measuring the Aesthetic / Visual Preferences of Large Groups.... - 12 -
   2.4 Structured Public Involvement Protocol to Support C.A.V.E. .......... - 15 -

3. The Milton-Madison Bridge Project Aesthetic Preference Process ........... - 17 -
   3.1 Overview .......................................................................................... - 17 -
   3.2 Physical Properties Linked to Visual Preference .............................. - 18 -
   3.3 Potential Bridge Locations, Distance and Design Preference ........... - 20 -
   3.4 Design Properties of the Visual Sample Set .................................... - 22 -

4. Visual Samples, Raw Scores, Subgroup Means, and Comments ............... - 26 -

5. Fuzzy Knowledge Builder: Preference Results for Public and Section 106 Parties...... - 36 -
   5.1 Arch Preferences .............................................................................. - 36 -
   5.2 Arches Summary ................................................................................ - 40 -
   5.3 Truss Preferences .............................................................................. - 41 -
   5.4 Trusses Summary ............................................................................. - 46 -
   5.5 Cable Stay Preferences ..................................................................... - 47 -
   5.6 Cable Stay Summary .......................................................................... - 49 -
   5.7 Overall Preference Summary ............................................................ - 50 -
   5.8 Public Satisfaction With SPI Process ............................................... - 51 -

6. References ................................................................................................ - 52 -
List of Figures.

Figure 1: Samuel Beckett Bridge in Downtown Dublin, Ireland ............................................... - 5 -
Figure 2: Arnstein's Ladder of Citizen Participation ................................................................. - 1 -
Figure 3: Existing and Desired Levels of Public Involvement .................................................. - 1 -
Figure 4: Artist's rendition of the Brooklyn Bridge at its opening. .............................................. - 9 -
Figure 5: Brooklyn Bridge photographed on a cloudy day at a distance. ................................... - 9 -
Figure 6: Interrelationship of Color with Complexity on Public Preference. ................................ - 1 -
Figure 7: The Milton Madison Bridge viewed from Milton, KY. ................................................ - 1 -
Figure 8: Summary of Design Language Used for Milton Madison CAVE Process ............... - 19 -
Figure 9: Viewshed Available from Madison Waterfront Park ............................................... - 21 -
Figure 10: Different Color Values and Their Impact In Context. ............................................. - 21 -
Figure 11: Milton Madison Bridge from Madison Riverfront Park ......................................... - 22 -
Figure 12: Coding and Summary of Ratings from Public and Section 106 members ............... - 22 -
Figure 13: Mean Preference Scores and Overall Standard Deviation of All Participants ......... - 23 -
Figure 14: Statistical Differences Between Public/PAG Scores and Section 106 Scores ....... - 24 -
Figure 15: Dark Color Value, Vertical Ribs, High Complexity, Profile = 2............................ - 26 -
Figure 16: Medium Color Value, Vertical Ribs, Low Complexity, Profile=2 ............................ - 27 -
Figure 17: Light Color Value, Vertical Ribs, Moderate Complexity, Profile=3 ........................ - 27 -
Figure 18: Dark Color Value, Inclined Ribs, Moderate Complexity, Profile=3 ........................ - 28 -
Figure 19: Moderate Color Value, Baskethandle, Moderate Complexity, Profile=2 ................. - 28 -
Figure 20: Light Color Value, Baskethandle, Low Complexity, Profile=2 .............................. - 29 -
Figure 21: Light Color Value, High Enclosure, High Complexity, Profile=2 ........................... - 29 -
Figure 22: Moderate Color Value, Moderate Enclosure, High Complexity, Profile=2 .............. - 30 -
Figure 23: Dark Color Value, High Enclosure, Moderate Complexity, Profile=1 ................. - 30 -
Figure 24: Dark Color Value, Low Enclosure, Moderate Complexity, Profile=3 .................... - 31 -
Figure 25: Moderate Color Value, High Enclosure, Low Complexity, Profile=1 .................... - 31 -
Figure 26: Light Color Value, Low Enclosure, Moderate Complexity, Profile =3 .................... - 32 -
Figure 27: Dark Color Value, Open Towers, Moderate Complexity, Profile =3 ....................... - 32 -
Figure 28: Moderate Color Value, Closed Towers, Moderate Complexity, Profile =3 ............. - 33 -
Figure 29: Light Color Value, Closed Tower, Low Complexity, Profile =3 ............................. - 33 -
Figure 30: Light Color Value, Closed Tower, High Complexity, Profile =3 ............................. - 34 -
Figure 31: Dark Color Value, Open Towers, Low Complexity, Profile=3 ............................... - 34 -
Figure 32: Light Color Value, Semi-Closed Towers, Moderate Complexity, Profile=3 ............. - 35 -
Figure 33: Bar Chart of All Respondents Satisfaction With This Process ............................... - 51 -
1. Project Properties That Impact Public Involvement

All large scale infrastructure planning and design projects are characterized by certain basic properties that affect the nature of the public involvement process. Each property presents a set of conditions that project managers should be aware of and prepared to respond to. In the specific case of major bridge design, these properties can be generalized to provide insight for the public involvement process. Important considerations include:

1.1. Time Scale of Project

Time scale matters in bridge design projects precisely because the bridge is designed to last for 75-100 years, and thus will serve as a very durable visual symbol for the area. It may also outlast some of the existing structures that form the current context for the bridge, including nearby bridges. Thus the current design context should be examined for its expected longevity versus the new bridge design.

1.2. Spatial Extent of Area Impacted By Project

Bridges are, by definition, clearly-defined, intentional links between areas that are otherwise more remote to each other. The geographic extent of these areas may be large, as in the case of a major bridge linking Interstate Highways, or more localized, as in a bridge across sensitive landscape to connect different areas of the same city. The impact area should be generally understood so that an effort can be made to involve the population throughout this area. Additionally, more local governmental agencies are likely to be involved and thus need to be included in the design process.
1.3. **Breadth and Depth of Public Impact**

Once the decision to build a bridge has been reached, the breadth and depth of impacts on the public can be better understood. The aesthetic impact could arguably be greater for those who will live and/or work in the viewshed of the bridge, however many urban bridges are also within the viewshed of public destinations such as riverfront parks or sporting facilities, and so have potential impacts more generally.

Aesthetic impacts can register against more than just straightforward individual preference. Because of the long lifetimes of most bridges, those that are being replaced already have an iconic association with their community, whether it is favorable or not. This iconography may be important to the identity of the community and thus be a factor in considering what sorts of designs might be most appropriate in the long term. The Golden Gate Bridge, Brooklyn Bridge, and the Roebling Bridge in Cincinnati are typical, much admired symbolic designs for their respective areas. Sometimes this symbolic shape is very deliberate, as in the new Samuel Beckett bridge in Dublin that invokes the shape of a harp, a national symbol of Ireland (Figure 1).
The public can also be impacted by non-aesthetic properties of particular design decisions. For example, constructability (the nature and extent of impacts that arise from the construction process) and maintenance activities over the life of the structure can have highly variable, if short term, impacts on different users. Many of these impacts are associated with transportation interruptions, either to traffic using the bridge or traveling near the bridge, or water-borne freight that passes through the bridge construction zone.

1.4. **Problem Complexity and Proliferation of Solutions**

Highly complex problems imply the interaction of many variables simultaneously, resulting in many theoretically possible solutions or outcomes. Bridge design involves a large set of technical limitations or parameters, discussed in the “Large Scale Bridge Design” section, which typically still allow many dozens if not hundreds of technically suitable designs that vary primarily in their aesthetic properties. Finding ways to coherently include the aesthetic preferences of the many people that will be impacted, regarding the many possible designs, is a major challenge of bridge design.

1.5. **The Type of Public Involvement in the Design Process**

There are many conceptual levels of public participation in any public infrastructure project, as first observed by Arnstein (1969). The authors have used Arnstein’s “Ladder of Participation” to measure the expectations of thousands of citizens and hundreds of professionals in public meetings around the country, regarding the most desired type of participation (Figure 2). The results are consistent: with great uniformity, the public and professionals alike desire to work in ‘partnership’ with each other on public infrastructure projects (Bailey, et. al. 2006).

![Figure 2: Arnstein's Ladder of Citizen Participation (Arnstein 1969)](image)

This fact is notable in that it negates the tension that is asserted between the design professional’s obligations and that of the public. Despite opinions to the contrary, (Gauvreau, 2005) we need not worry that somehow the public expects to ‘take over’ the process and dictate unreasonable or impractical designs. Their expectation is merely that their preferences will be incorporated into the overall design process (Figure 3).
The design team may be tempted to simplify the extent of public involvement as a presumed strategy for simplifying the design problem. This approach may manifest itself by limiting participation to an advisory panel for aesthetic preferences (instead of full public meetings), presenting a limited set of design choices to be evaluated, or both strategies simultaneously. These approaches are not necessarily the best way to achieve effective community and stakeholder design (Subcommittee on Bridge Aesthetic Design, 2009, p. 48-49).

Finding ways to incorporate large, or multiple, group preferences into the design problem in a ‘partnering’ sense is more challenging. Large groups typically imply a greater variety of preferences to be understood and then reconciled. Further, professionals still face the challenge of how to gather the preferences regarding many hundreds of possible designs in a time-efficient and coherent way that is helpful to the design professionals (Zuk 1995).

Also involved in this problem are formally responsible parties under the NEPA process such as the Sec. 106 Historic Preservation consulting parties. They are assigned the responsibility of assessing any historic preservation impacts that arise out of the project. Given that most bridges are over 50 years old, and younger bridges are sometime found in historic contexts, bridge replacement has important historic preservation implications. While the application of inappropriate historic ‘treatments’ to a modern structural type is discouraged, the replacement of a particular structural type with a similar type, or with similar structural appearance, is endorsed (Subcommittee on Bridge Aesthetic Design, 2009, p. 52-53).
2. Large Scale Bridge Design

2.1 Typical Constraints On the Bridge Design: The “Design Envelope”

With every bridge design, there is a set of technical requirements that place approximate boundaries around the family of possible or practical designs. Having a clear understanding of the ‘design envelope’ then facilitates the creation of the set of possible design concepts within that envelope. These constraints can each have an impact on the visual effect of the resultant designs that must conform to them.

Performance/Capacity: Each bridge exists because a decision was made to provide a certain amount of linkage capacity between distance spaces. The type, quality, and volume of this capacity are the guiding requirements of the design envelope. Currently in the U.S., most proposed new bridges are meant to improve on capacity and quality deficiencies (too few and too narrow lanes, too few modes), or sometimes structural hazards. As the structure becomes wider, the proportions of the bridge change along with the size of the structural supports, both of which are important to the visual impact of a design.

Bridge Location: The details of the precise location of a proposed new structure have physical implications for modifications to the surrounding landscape, both in terms of transportation linkages and the impact of the approach on the existing landscape. Alternative bridge locations have different implications for visual impact. The appeal of nearer, larger, more visually distinct structures may be different when they are further away, visually smaller, and the details of their shape are softened by intervening blue atmospheric scatter or atmospheric phenomenon such as rain, snow, or smog.
Measuring Milton-Madison Aesthetic Preferences

Figure 4: Artist's rendition of the Brooklyn Bridge at its opening. This brightly lit perspective emphasizes the monumental aspects of the design. From *Art of the Brooklyn Bridge: A Visual History* by Richard Haw, 2008

Figure 5: Brooklyn Bridge photographed on a cloudy day at a distance. This perspective and light condition makes the bridge appear more graceful and softens the contrast against the sky. From *Art of the Brooklyn Bridge: A Visual History* by Richard Haw, 2008

Pier Location and Spacing: These major structural elements can constitute barriers to barge traffic in a river, railroad or highway construction, or undesirable additions to riverfront parks or in neighborhoods. In navigable water, pier locations are specified by the United States Coast Guard to accommodate barge traffic.

Pier locations affect the basic structure of the bridge, because they then define the number and length of spans, which in turn drives the nature of the structural design that
must bridge that span. Other things being equal, arches, trusses, and cable stay towers become taller as they are used to cross greater spans. Pier location also affects the pattern of the structures, as the spacing of piers cannot generally be expected to be equidistant. Combining unequal span lengths can create a situation where the most ‘efficient’ design is one with varying heights among the structures.

Water Clearance: Additionally, the United States Coast Guard typically specifies the navigation requirements of major river bridges by imposing a water-to-structure minimum vertical clearance, which may vary heights appropriate for river barges, up to many hundreds of feet if the bridge must clear major ocean-going vessels. This affects the relative proportions of the superstructure to the piers underneath and thus affects the visual impression of the structure.

Context: If a bridge is to be built next to an existing bridge, as a way of expanding capacity, the visual appeal of the new design will be affected by how it coordinates with the existing bridge. Deck height differences will be noticeable, contrasts in structure type will be evident, and even the number and nature of inflections in the profile of the structures will be highlighted. In some cases, it may be appropriate to consider different bridge designs with, and without, the accompanying bridge, on the assumption that the current bridge will be outdated before the new one. If the context is one of bridge replacement, this may be an opportunity for residents to re-think what type of prominent structure shape they would like associated with their community.

Cost: Every bridge has a budget. Unfortunately, detailed cost information about a family of concepts is typically not available at the beginning of a process, and may in fact be a moving target due to the changing prices of steel, concrete, and other basic materials. Cost may be affected by the nature of the substructure(s) the bridge is built on, something that is often not fully known at the beginning of a project. Ultimately, the factor of cost is the responsibility of the sponsoring agency(s). Under ideal conditions, cost can be weighed against appeal or preference to identify the most advantageous design possible for a given budget, and thus realize the most value for dollar. Thus it is important to conceptually separate people’s aesthetic preferences cleanly from any notion of cost when gathering data, so that pure ‘value’ can be accurately assessed by professionals against cost and the other considerations discussed here.

Construction Issues and Methods: As mentioned earlier, different design choices entail different construction processes, which in turn have differential impacts on roadway and waterway traffic. In the most benign case, a new structure can be put in place near the existing one with minimal interruption of roadway traffic. However, certain structural designs cannot be built in situ, and must be pre-fabricated and moved into position in large units.

Life Cycle (Maintenance) Costs: Each bridge design has a unique set of maintenance requirements, some of which are not yet well understood. Because we now have experience with a great number of different styles of steel truss bridges, dating back across many decades, our understanding of the long-term maintenance needs of these
types of bridges is fairly sophisticated. Conversely, our experience with cable-stay bridges is much more recent, and we are only now beginning to learn about the potential for different kinds of potential maintenance needs in them. Newer designs are thus the source of more uncertainty about life cycle costs.

### 2.2 Process Guidance from Bridge Designers

The bridge design community offers a great many visual terms and concepts to the bridge designer. The draft Bridge Aesthetics Sourcebook (Subcommittee on Bridge Aesthetic Design, 2009) suggests a list of **Visual Characteristics**; that is, a list of descriptors that point to distinct physical properties. This list includes: Line, Shape, Form, Color, Texture, and Shade and Shadow. Unfortunately, the Sourcebook does not suggest substantial distinctive categories for each of these visual characteristics, so that there is no list of shapes, textures, or forms for a designer to refer to. Of these, only color, with a pre-existing set of values, could be considered to be described fully by the designer, and textures can and have been ordered and categorized for different uses in the design professions. It is conceivable that other classification schemes could be applied to some of the remainder of the terms. Also, the sourcebook suggests a set of **Visual Qualities**, including Order, Proportion, Rhythm, Harmony, Balance, Contrast, Scale, Illusion and Unity. The Sourcebook observes that these qualities are “perceived characteristics that exist only in the mind of the evaluator” (Subcommittee on Bridge Aesthetic Design, 2009, pp. 37-45). Unfortunately, there is little specific guidance regarding how these terms or visual qualities are to be deployed in order to improve the design of a given bridge. There is no guideline, for example, regarding whether or where to attempt to invoke high or low Contrast in a design. These terms appear to be intended for use by bridge designers, but seem to have limited usefulness for the general public, given their rather nebulous descriptions.

Some designers have been more direct in their opinions about bridge design. A review of the bridge design literature in the mid-90’s offered some generalizations from that experience. These observations include:

- The arch is generally considered to be the most pleasing of all bridge forms
- The truss is generally considered to be the least pleasing of all bridge forms
- The overall form of a bridge should be simple
- The girders, piers, and railings of a bridge should generally appear slender
- Large expanses of concrete surfaces of a bridge should be textured
- A concrete bridge should be colored in such hues as off-white, tan, reddish brown, or gray if possible.

There were other less specific observations as well:

- A bridge form should clearly express its structural function
- All elements of a bridge should be visually unified
- A bridge form should harmonize with the dominant features of its site (Zuk 1995, p. 45).
Other, more recent works continue in this vein. Gauvreau (2002) offers the “three myths of bridge aesthetics” wherein he argues that a.) efficient structural forms are not necessarily the most aesthetically pleasing; b.) the public’s aesthetic taste is not to be trusted; and c.) bridge engineers are just as good as designers as architects are. While the reader may or may not agree with these ideas, it is difficult to see what specific guidance regarding bridge aesthetics is to be derived from them.

2.3 Approaches to Measuring the Aesthetic / Visual Preferences of Large Groups

Interest in the visual properties of bridges dates at least to the 1970’s, when an engineer started asking drivers, residents, and ‘artistically trained’ individuals about their preferences for various paint colors on a pair of real-world bridges (Zuk, 1974). This logic has been expanded to test multi-criteria methods for evaluating structures, a so-called ‘expert system’ (Zuk, 1995). Even in current research on transportation and aesthetics, many methods draw on the opinions or input of experts for the definitions of high quality aesthetic value (eg. Chen, Abdel-Aty, Huang, and Ma, 2010). Methods that are aimed at including large groups of people concentrate more on the visualization capabilities of the outreach tool than the method, nature or meaning of the feedback (Brabham, Sanchez, and Bartholomew, 2010).

Testing the aesthetic appeal of alternative bridge designs in the real world is essentially impossible, due to the highly variable nature of the contexts and existing examples of bridges. Consequently, most visual analysis must rely on various representation tools such as photo simulations or virtual dynamic models. Dynamic visual evaluation is defined as real-time evaluation of visualizations of end-states containing an interactive element, both in the presentation media and in the value elicitation framework, allowing the team to elicit, document and evaluate the interpretations provided by stakeholders. There are several methodological issues associated with visual scenario evaluation by large groups. Table 1 shows properties of three visual evaluation methods.

<table>
<thead>
<tr>
<th>Visual assessment method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional visual assessment</td>
<td>Intuitive</td>
<td>Unstructured.</td>
</tr>
<tr>
<td>Visual Preference Survey (VPS®)</td>
<td>Rapid scoring</td>
<td>Marginal discrimination unreliable</td>
</tr>
<tr>
<td></td>
<td>Intuitive</td>
<td>No analytic method</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not open for public inspection</td>
</tr>
<tr>
<td>Exhaustive pairwise comparison</td>
<td>Explicit elemental scoring</td>
<td>Too data-hungry</td>
</tr>
<tr>
<td></td>
<td>Reliable marginal preference discrimination</td>
<td>Far from intuitive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Potential for inconsistency (i.e. preference intransitivity)</td>
</tr>
</tbody>
</table>
There are conflicting goals for visual evaluation. The need for a high volume and quality of input data from a large number of participants must be balanced against the cost and time involved in preparing and acquiring this data. The need for a large number of samples must be balanced against logistical and feasibility considerations for each meeting. The desirability of interval or ratio numerical quality inputs for statistical and numerical analysis must be balanced against the seamless functioning of human perception and cognition systems. These factors must all be taken into account during process design and selection of visual method.

Many of the problems associated with large-scale group visual evaluation are associated with the reality of hosting large public meetings. A key constraint in real public processes is the useful time available. The authors have hosted over one hundred public meetings dealing with infrastructure issues and 90 minutes is an upper bound for this evaluation. Less than 60 minutes is preferable. Experience shows that between twelve and twenty-five visualizations can be evaluated effectively during this timeframe, depending on whether these are still images, animations requiring run times prior to evaluation, or complex decision problem combining diverse and abstract factors. The extent of post-scoring focused verbal evaluation of specific visualizations and their properties must also be considered in the time budget.

Traditional visual assessment consists of showing a set number of images to respondents and eliciting unstructured verbal feedback, or ordinal rankings. This method is cheap and easy to implement. It is often employed by consultants and designers for large group evaluations of design proposals. However, despite its convenience, it is a data-poor way to evaluate preference. It leaves unanswered the questions of how specific design elements are influencing public valuations, and in which combinations, and it does not address the problem of preference intransitivity.

The Visual Preference Survey, or VPS® (Nelessen 1994) is widely used by architects, designers and public involvement practitioners for visual evaluation of structures and built environments. It consists of rapid evaluation of images on an integer Likert scale and is quick and intuitive. However, the interpretation of the data, and the way in which elements interact with one another, is left to the minds of the survey designers. No database is generated and third-party analytic inspection of community values in relation to the design elements is not possible. The success of this system depends strongly on the participating group’s trust of the individuals administering and interpreting the survey, and of the designers’ understandings of how people react to composite scenarios.

Marginal discrimination is most effectively maintained by performing exhaustive pairwise image comparison (e.g. Whitmore, Cook and Steiner 1994, Zube 1994). Despite the quality of the analysis, this evaluation method is not viable when a realistic number of design elements exists. This is because, even with few design properties, hundreds of potential combinations exist. Environmental design research of this type is often conducted with captive subjects such as students or advisory panels (e.g. Whitmore,
Cook and Steiner 1994, Stamps 1999, Zuk 1995). However, the expectations of large numbers of citizens attending open public meetings cannot be met in this way. Therefore, the problem domain is challenging. Standard statistical methods cannot generate useful properties with such small sample sizes and limited coverage of the state space.

If exhaustive evaluation is not possible, it follows that the visual evaluation decision support system therefore needs to be able to convert the information from a smaller sample set into a function that will predict outputs for all possible input combinations i.e. it will estimate stakeholder preference for scenarios that may not yet have been modeled or tested, if such scenarios can be defined from feasible combinations of the input parameters.

Fuzzy set approaches have been used effectively to model analogous nonlinear systems under conditions of sparse data and high uncertainty (e.g. Zadeh 1965). This is a very efficient process because it eliminates the need to score all possible combinations of inputs. It also provides more analytic information than traditional visual assessment or the Visual Preference Survey.

The authors designed a fuzzy-set based system modeling approach called Casewise Visual Evaluation, or CAVE, (Bailey et al. 2001). The CAVE system takes the output, y, i.e. mean stakeholder preference for the scenario, and maps this output to the known inputs $x_1, x_2, x_3...x_n$, which in this case are the structural / visual parameters that define the properties of each concept. A relatively small set of sample evaluations can be used to generate a community knowledge base covering all potential configurations. The research team and project managers can then inspect this knowledge base, examining the sensitivity of stakeholder preferences with respect to various input parameters. The software \textit{FuzzyKnowledgeBuilder} is used to build the community knowledge base. A series of neural network algorithms are employed to build outputs around the known points. The functions are compiled and saved as a multidimensional mapping function that relates the output to all of the inputs across the entire range of every input parameter. Once built, the community knowledge base exists as a multi-dimensional inputs-output model that can be interrogated by the design team across this full range of all input parameters. The community knowledge base now functions as a decision support system. It allows the evaluation of performance of designs with respect to the z output, and allows for trade-off analyses, or constrained optimizations, to be performed in cases where the community knowledge base must interoperate with other factors e.g. cost, or areas of the design envelope that are not feasible for constructability reasons, etc.

Various tools exist to facilitate the inspection of the community knowledge base. A knowledge slicer allows a 3D graphical output to be presented. Two input variables ($x_1, x_2$) are presented across their entire ranges, and the output ($z$) is mapped to a surface. Figure 3 shows a sample output. While the entire model includes 5 variables, the interrelationship of two of those as they affect preference can be explored while the other three are held constant.
Exhaustive inspection of a range of these surfaces allows the team to interpret likely public response to changes in one input parameter, with all other inputs held constant. By working sequentially through each input, high spots, or combinations that community values highly, can be identified. Also “sinkholes” or undesirable areas in the design envelope, can be identified. The outputs are categorical, corresponding to numerical ranges for each parameter. The principle behind fuzzy logic application is the trading of false precision for greater accuracy between broader categories of output. For example, this means that, unlike a multivariate statistically-based analysis, discrimination based on numerical outputs within a given class is not reliable. However, the discrimination between categories is robust. Normally, five categories or more are used to map output ranges. It must be borne in mind that this method is not directly comparable to standard statistical approaches to visual decomposition, because statistical methods cannot function at all with such limited data.

2.4 Structured Public Involvement Protocol to Support C.A.V.E.

The Structured Public Involvement protocol for bridge design allows public input on aesthetic value to be gathered and incorporated into the design process at the beginning. The public is able to see their results in real time and understand how their input is being used as the design process advances. To accomplish this, the protocol uses a carefully selected array of bridge design concepts to gather public input with. This array of concepts is chosen from a ‘design envelope' that accommodates the cost, performance, construction, and maintenance requirements for the bridge. Thus, all public input on bridge design is within the boundaries of the project. The number of concepts tested depends on the complexity of the design envelope, but would typically be about 20-25. All preference data is gathered using an anonymous audience response system A.R.S. that can accommodate up to 250 people simultaneously. It is also a reproducible process, so that equivalent data can be gathered in a series of
meetings from a broad range of citizens and then compiled. Larger numbers of participants actually improve the quality and reliability of the results, unlike some public processes where larger numbers of participants can create difficulties. The SPI process has been used successfully with groups as large as 300 in large bridge design problems, and with up to 90 simultaneous participants in other planning and design applications.

At the meetings, participants are informed about the aspects of the design that are not negotiable for the reasons mentioned above, and other logistical, practical and legal reasons. By explicitly establishing the portion of the design envelope which the public can influence, the process avoids mismatched expectations causing frustration on all sides. In exchange, the design team gains useful data regarding aesthetic parameters.

Essentially, the SPI approach responds to the spirit and the letter of original FHWA guidance, “public input must drive and inform the technical process” as promulgated during transportation funding legislation in the early 1990’s. By designating, in broad terms, public input as the originating determinant for technical work related to transportation solutions, federal guidance of the time opened opportunities for a more collaborative, true context sensitive design approach to transportations solutions.

The full SPI approach, described herein works hand in hand with the values and practices of good context sensitive design, taking into account project parameters along with design practices and adding the concept of levels of preference for alternatives as opposed to voting or choosing among alternatives. Asking the public to express preference for a bridge concept and then actual alternatives is in line with a spirit of collaboration that leads to informed consent for an ultimate solution.

Further federal guidance calls for a varied menu of techniques that deepen the sorts of inputs from the public. SPI, as applied here, provides a rare innovative public involvement technique for soliciting and analyzing public preference and can now be added to the menu of techniques available for comprehensive, targeted, strategic public involvement programs for complex projects of many kinds.
3. The Milton-Madison Bridge Project Aesthetic Preference Process

3.1 Overview

The Milton-Madison bridge replacement project takes place in the context of a Main Street America town, Madison, IN, with a significant historic preservation community and a reputation for preservation of the historic fabric of the town. On the Kentucky side is the smaller community of Milton, KY. The bridge over the Ohio River serves primarily as a link between the two communities, not as a major regional commercial freight connection. Due to its age, size, and condition, it was judged to be insufficient in capacity and structurally deficient, and thus a candidate for repair or replacement. It is situated prominently in the viewshed of the riverfront park built by Madison, IN, and hosts a regatta each summer. It is an inescapable feature of the Milton and Madison cultural and historic landscape (Figure 7).

There was no necessary requirement that the replacement bridge be located at or near the existing structure, and indeed many different options existed, at least in theory, for bridge location.

This, then, would have important visual preference implications as the structure was placed nearer, or further, from the main body of each town. Visual perception and thus preference would be influenced by the interplay of different structural features, different colors, proximity, light angle, time of day, atmospheric conditions, and so on.

There are also no requirements embedded in the NEPA process that dictate the design of a bridge that should replace one of this age, merely a requirement for adequate public process for making the decision. The Kentucky Transportation Cabinet and the Indiana Department of Transportation chose, in the interest of ensuring citizen and...
historic preservation satisfaction, to engage the University of Kentucky in the deployment of the CAVE method for measuring citizen preferences for bridge design, and to partition these preferences further by the Section 106 consulting parties and the general public.

On February 12, 2009, approximately 165 citizens of Milton, Kentucky and Madison, Indiana attended a bridge location and design public meeting held in the Brown Gymnasium in Madison, Indiana. Included in the attendees were the Public Advisory Group and the Section 106 Historic Advisory Panel. After other meeting items were attended to, all participants were invited to view, discuss, and rate the suitability of a set of 18 bridge design concepts. Their task was to rate each concept for its suitability in the context of replacement for the existing 1929-era bridge. Meeting organizers contracted with the U. of Kentucky Transportation Center to provide a Structured Public Involvement protocol for purposes of identifying the level and type of preferences of the attendees for various combinations of bridge design properties.

Using the CAVE method, the authors gathered rating data from the participants regarding 6 arch, 1 truss-arch, 5 truss and 6 cable stay concepts. These concepts varied in their visual complexity, color value (lightness to darkness), type of enclosure created by the superstructure, and the overall profile of the structure. This data, together with the preferences gathered from the general audience and the data gathered from the 106 panel, was modeled, so that designers could better understand the trade-offs between cost, constructability, maintenance, and visual preference by citizens.

### 3.2 Physical Properties Linked to Visual Preference

As discussed before, a considerable challenge is linking descriptive aesthetic bridge design terms to specific design decisions. Most of the literature aimed at professionals is unhelpful in this regard, and thus even more so for the general public, unversed in the language of design. However, the authors have, over time and with experience, developed a language of physical properties that are linked to changes in visual preference, thus allowing the interaction between design properties and large group preferences to be recorded quantitatively, and more importantly, modeled for future use.

This 'language' is a way of agreeing that specific visual properties have specific meanings, within the context of a particular project, so that designers can communicate clearly during the design process. ‘High’, ‘medium’ and ‘low’ have specific values relative to the range of potential superstructure heights for a specific bridge project, which is probably different than the values for a different project. Nevertheless, they serve as a common, specific comparative language for the design team. Similarly, concepts such as low, medium, and high visual complexity are also assigned agreed-upon meanings by the design team, so that discussions about design modifications can be coherently communicated.

This language shares some common properties across different bridge design problems, but allows for new design language to be inserted when it is likely to be visually important. Thus, certain fundamental physical/visual properties are always a
Structural type is a fundamental difference that is unambiguous except in the case of a truss arch, which is technically a truss but is visually in the shape family with arches. For the length of span dictated by the pier placement in the Milton-Madison problem, the design envelope permitted trusses, arches, and cable stay types.

Similarly, another frequently mentioned visual property is ‘simplicity / transparency / slenderness.’ The design team has encapsulated this idea into the concept of visual complexity, with values that can range from low to high, with as many intermediate definitions as are deemed necessary. For the Milton-Madison project, three distinct levels of complexity were agreed to be sufficient to capture the variability across the different structures.

Another design property that has significant impact on the visual impressions of the observer is the nature of the enclosure effect created by the superstructure above the deck. This enclosure effect is the least when arch ribs or cable stay towers are vertical, and increases as the ribs or towers incline toward each other or are linked somehow at the apex. For truss designs, this enclosure effect is the least when the truss is the most open inside, with more vertical distance to the top, and less when the truss is lower.

Another property of this particular bridge design problem that the team wanted to characterize was the number of inflections in the topline of the bridge superstructure. This was characterized by the number of arches, towers, or truss haunches present in the design. For purposes of this project, the relevant categories were set at 0, 1 and 2 or more.

Finally, the design team wanted to capture the effect of different color values (light, medium, or dark) as they interacted with the other structural properties. A wide range of color tones and values have been applied to bridges, and some advice has been given about the ‘best’ colors to use. However, the interaction of color value with other structural properties such as visual complexity, and the potentially confounding impacts of distance and thus atmospheric blue scatter on color perception made this a more important variable than in past projects (Figure 8).

---

**Model Coding From FKB**

<table>
<thead>
<tr>
<th>Numeric Code</th>
<th>Bridge Type</th>
<th>Complexity</th>
<th>Color Value</th>
<th>Profile</th>
<th>Enclosure</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>Arch</td>
<td>Low</td>
<td>Light</td>
<td>0</td>
<td>“A” or Truss Low</td>
</tr>
<tr>
<td>500</td>
<td>Cable</td>
<td>Medium</td>
<td>Med</td>
<td>1</td>
<td>“H” or Truss High</td>
</tr>
<tr>
<td>750</td>
<td>Truss</td>
<td>High</td>
<td>Dark</td>
<td>2+</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8: Summary of Design Language Used for Milton Madison CAVE Process
3.3 Potential Bridge Locations, Distance and Design Preference

As discussed earlier in the report, the visual effects of atmospheric scatter ("blue haze") and the specific visual context are both possible influences on visual preference for any given design. This haze is due primarily to humidity, especially in the eastern US, and tends to introduce progressively more neutral ‘blue’ into objects as they are further away. On cloudy days this color is closer to neutral grey, a product of the color of the sky. In either case, objects painted neutral tones will be less visually prominent with increasing distance, as compared to objects that are at the light or dark portions of the color value scale. Thus, for example, a neutral grey truss bridge that is located one half mile or more distant from the current location is likely to be less prominent than the same bright (or dark) truss bridge at the current location because of the combination of color value and distance.

Also, the angle of the viewers’ perspective of the bridge is lowered as it is considered at successively greater distances, so that the darker hills of the Ohio River Valley provide a greater proportion of the background for the bridge. Because these values will be closer to the medium and dark end of the scale, medium or dark colored designs would similarly recede in prominence as they dip below the horizon (Figure 10, top). The combination of low viewing angle and atmospheric scatter that increasing distance yields, in this context, would act together to yield a more rapid decrease in visual contrast than either alone.

A further complicating factor regarding potential bridge locations and visual impact is the shape of the river course. The Ohio River makes a distinct turn to the left upstream, thus placing any contemplated structure largely out of view from the Madison shore, and partially obstructing the view from the Milton shore (Figure 9). Given that the major visual impact is meant to be measured from locations where there are the greatest number of viewers, the project team agreed that testing the bridge designs at this distant location would likely yield very little useful data. Other candidate bridge locations were within a reasonable distance of the existing structure, so that scatter and the viewing angle would not be a significant factor in the visual impressions. As a result, the tests of visual preference were conducted using the new candidate concepts at the existing bridge site.
Figure 9: Viewshed Available from Madison Waterfront Park

Figure 10: Different Color Values and Their Impact In Context.
3.4 Design Properties of the Visual Sample Set

Using the sample coding described above, 18 different bridge concepts were prepared for testing with the audience. Because different perspectives yield different impressions, three views of each concept were prepared: one from the Madison Riverfront Park downstream of the structure (Fig. 11), one from the upriver perspective on the Milton side (Fig. 7), and one for a typical driver just entering the superstructure on the bridge.

![Figure 11: Milton Madison Bridge from Madison Riverfront Park.](image)

Each of the designs was a unique combination of the visual/physical properties described above. Mean preference scores were identified from the desired subgroups and grouped accordingly (Figure 12).

<table>
<thead>
<tr>
<th>Design</th>
<th>Citizens and PAG Mean</th>
<th>106 + 106andPAG Mean</th>
<th>Type</th>
<th>Profile</th>
<th>Complexity</th>
<th>Enclosure</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>4.35</td>
<td>2.94</td>
<td>L</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>4.05</td>
<td>2.50</td>
<td>VL</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>A3</td>
<td>5.36</td>
<td>4.16</td>
<td>ABO</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>4.46</td>
<td>3.65</td>
<td>OK</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>A5</td>
<td>3.67</td>
<td>2.74</td>
<td>L</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>A6</td>
<td>4.36</td>
<td>3.20</td>
<td>BEL</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>T1</td>
<td>3.77</td>
<td>4.20</td>
<td>ABO</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>T2</td>
<td>2.52</td>
<td>4.20</td>
<td>L</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>T3</td>
<td>1.99</td>
<td>2.40</td>
<td>VL</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>T4</td>
<td>3.36</td>
<td>5.25</td>
<td>VL</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>T5</td>
<td>1.59</td>
<td>1.90</td>
<td>ABO</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>T6</td>
<td>4.90</td>
<td>6.80</td>
<td>VH</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>C1</td>
<td>5.33</td>
<td>4.35</td>
<td>ABO</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C2</td>
<td>5.82</td>
<td>4.65</td>
<td>H</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>C3</td>
<td>5.50</td>
<td>5.00</td>
<td>VH</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C4</td>
<td>6.11</td>
<td>4.65</td>
<td>H</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>C5</td>
<td>4.91</td>
<td>3.75</td>
<td>OK</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C6</td>
<td>6.45</td>
<td>4.95</td>
<td>L</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 12: Coding Description and Summary of Ratings from Public Input (Green) and all Section 106 members (violet)
This selected set of scores was generated from the more detailed data that was gathered at the meeting, wherein preference data from the general public, the Public Advisory Group, and the members of the Section 106 Consulting group were gathered simultaneously. Those disaggregated data follow (Figure 13.)

![Scoring Summary and Standard Deviation by Groups](image)

**Figure 13: Mean Preference Scores (Lines) and Overall Standard Deviation (Vertical Bars) of All Participants in Milton Madison Bridge Preference Scoring Meeting.**

Some general observations can be made about these results.

- Subgroup means tended to be more extreme than the overall group mean (‘Grand Total’ line)
- Lower average preferences coincided with lower standard deviations: i.e. people agreed more uniformly about what they disliked than what they liked
- Cable stays (C1-C6) exhibited the highest mean preference scores, arches were next most preferred, and trusses, as a group, yielded the lowest mean preference scores
- Mean preference scores for the Sec. 106 group were wider than other groups
After inspecting the data of the various subgroups, it was determined that the data gathered from all Section 106 consulting party members was markedly statistically different from the rest of the participants (Public and PAG members), while the mean scores of the PAG members were not sufficiently statistically different from the Public averages to yield a usefully different preference model (Figure 14). Therefore, two preference models were constructed: one that reflected the preferences by the Public and PAG members, and a second one that reflected the measured preferences of all Section 106 members, including those who were also members of the PAG. It should be noted that even though most of the Public vs. Sec. 106 means were statistically different, only two of the eighteen differed in direction. That is, for 16 of the 18 samples, those that were scored above “OK” by the public and those that were scored below “OK” by the public were corresponding scored in the same direction by the Section 106 group (Figure 12). The rest of the differences were in degree of preference or non-preference.

**Figure 14: Statistical Differences Between Each Public/PAG Mean Score and the Section 106 Mean Score**

There are also some observations to be made about the composition of the sample set. Although the coding scheme could accommodate ‘Profile’ values of “0”, “1”, or “2+”, not all combinations of these profiles were tested across all structure types. Only two-tower cable stays were deemed suitable for the site by the sponsor, and a maximum of two arch spans were deemed suitable by the sponsor. Also, because of anticipated cost
impacts, cable stay towers were only tested in the “Light” category of Color Value, although the decks of the cable stay concepts were allowed the full range from “Light” to “Dark.” Finally, one of the concepts was a truss arch, meaning that while its structural properties were that of a truss, the appearance of the shape (visual property) was that of an arch. Thus the sample set was unevenly distributed with a total of six cable stays, seven arches, and five truss shapes.

Despite these qualifications, the data was of sufficient quantity and quality to allow the two desired Knowledge Base models to be derived by the authors. The development of the models is an iterative process of selectively testing a series of data series estimating methods to arrive at a model that is consistent with observed data and adequately captures the information relevant to characterize expected preference for the unobserved design configurations.

What follows is a series of four modules. The first module supplies the data gathered for all of the three basic structural types: cable stay, arch, and truss. The Madison Riverfront View of each visual sample is supplied for reference, along with the rating supplied by the public, and the Sec. 106 consulting parties, and a bar graph of the overall combined score. Note that for model building purposes, the output was characterized into one of seven categories: Very Low, Low, Below Average, OK, Above Average, High, Very High. Since the range for the Sec. 106 scores was wider than that of the Public’s, however, the same numeric score across the two groups may represent a different comparative level of preference within the subgroup, or different numeric scores across groups may actually be representative of the same comparative level of preference within each group, as for example Arch 4.

Following the image and scoring module are three modules from the Knowledge Base that each relate to one structural type, in turn, and how the other properties interact with preference. The same slice is presented for the Public group and the Sec. 106 group to enhance visual comparison. Following each module are some summary comments regarding that particular structural type. Following each of the three modules is a discussion of the overall model results and implications for the design problem.
4. Visual Samples, Raw Scores, Subgroup Means, and Comments

The visual samples are presented here in the same order they were presented to the participants. Structural types were grouped together to allow participants to more easily discriminate the sometimes subtle differences between similar major structural types. Additionally, discussion about the various features and properties of the major structural types was facilitated by having examples of various types and treatments grouped together in the presentation. Bridge design professionals presented and discussed each visual sample in turn, and answered any questions regarding each sample. All eighteen visual samples were presented and discussed before any scoring was requested. The facilitator then asked the participants for verbal confirmation that they were sufficiently prepared to supply their aesthetic preferences using the ARS. A short familiarity routine was performed to ensure that everyone could adequately operate the ARS, and then the scoring phase commenced.

Figure 15: Dark Color Value, Vertical Ribs, High Complexity, Profile = 2
Figure 16: Medium Color Value, Vertical Ribs, Low Complexity, Profile=2

- It is simple
- Like the color
- It is transparent
- Like the two spans
- It has fewer piers
- Like the historic (arch) and modern feel
- It is curvilinear and unobstructed
- It fits the space nicely
- It looks low maintenance
- It matches the bicentennial theme (two arches)

Figure 17: Light Color Value, Vertical Ribs, Moderate Complexity, Profile=3

- It is simple
- Like the color
- It is transparent
- Like the two spans
- It has fewer piers
- Like the historic (arch) and modern feel
- It is curvilinear and unobstructed
- It fits the space nicely
- It looks low maintenance
- It matches the bicentennial theme (two arches)
Figure 18: Dark Color Value, Inclined Ribs, Moderate Complexity, Profile=3

Figure 19: Moderate Color Value, Baskethandle, Moderate Complexity, Profile=2
Figure 20: Light Color Value, Baskethandle, Low Complexity, Profile=2

Figure 21: Light Color Value, High Enclosure, High Complexity, Profile=2
Figure 22: Moderate Color Value, Moderate Enclosure, High Complexity, Profile=2

Figure 23: Dark Color Value, High Enclosure, Moderate Complexity, Profile=1
Figure 24: Dark Color Value, Low Enclosure, Moderate Complexity, Profile=3

Figure 25: Moderate Color Value, High Enclosure, Low Complexity, Profile=1
Figure 26: Light Color Value, Low Enclosure, Moderate Complexity, Profile =3

- Like the light color
- It resembles the current bridge which is good (2 comments)
- It looks historically appropriate
- Like the design that goes all the way across the river
- The superstructure may interfere with the views looking through it
- The shape compliments the hills
- This could be for the “tri-centennial” (three peaks)
- It looks less expensive with fewer piers
- Fewer piers mean less obstruction for river traffic

Figure 27: Dark Color Value, Open Towers, Moderate Complexity, Profile =3
Figure 28: Moderate Color Value, Closed Towers, Moderate Complexity, Profile =3

Figure 29: Light Color Value, Closed Tower, Low Complexity, Profile =3
Figure 30: Light Color Value, Closed Tower, High Complexity, Profile =3

- The straight piers are appealing
- The dark color may have a negative influence on the rating of the style
- It looks like rabbit ears
- It is too geometric for the topography
- The cable-stays emphasize the future
- The radial cables are better than the harped (parallel) ones

Figure 31: Dark Color Value, Open Towers, Low Complexity, Profile=3
Figure 32: Light Color Value, Semi-Closed Towers, Moderate Complexity, Profile=3

For each of the concepts, we reproduced the comments offered from the participants. Note that comments about the same structure may be complementary or contradictory, depending on the views of the individual. Some comments were abstract, regarding the extent to which a concept suggested the future or the past, and others were pragmatic, reflecting on the impact on viewshed, and some were iconic “it looks like rabbit ears.” Frequently the distribution of scores was quite broad, reflecting the reality of most diverse groups, yet certain concepts could be seen to be more popular than others, and one or two garnered nearly universal scorn. Note that positive and negative reactions are equally useful in building a model of group preference, so that a wide spread of opinions is more useful than a narrowly-grouped set of sample with similar preference ratings. The process did succeed in measuring a wide divergence of opinion. This foregoing data was then used to build the Knowledge Base models we will compare and discuss in the next section.
5. Fuzzy Knowledge Builder: Preference Results for Public and Section 106 Parties

This section will present and discuss paired preference surfaces for the same portion of the design preference model. The first surface will be that modeled for the Public Preferences, the second for the Sec. 106 Consulting Parties.

5.1 Arch Preferences

These two surfaces demonstrate moderate (light blue) to high (dark blue to pink) preference (PREF) for twin arches with vertical ribs, with Sec. 106 Parties somewhat more favorable toward high complexity (CPX), darker designs (COL) than the general public, which uniformly preferred light colors regardless of complexity.
Moderately inclined, twin arches were also moderate to above average preference for both the Public and Sec. 106, with a slightly lower favorability for high complexity, light color and low complexity, dark color by Sec. 106.
“A” shaped twin arches were more uniformly preferred by the Public, while Sec. 106 had a lower opinion when the arches became more complex, darker, or both.
Single arch preference surfaces generally had lower preference areas in them than twin arch preferences. Both Arch 6 and Arch 5 were noticeably less preferred by both groups. Preference appears to improve by both groups for single arches with moderate color value and moderate complexity.
“H” or vertical rib single arches appear to benefit from combinations of higher complexity and darker color, but increases in either one individually do not appear to usefully improve preference for either group.

5.2 Arches Summary

Our results showed that twin arch designs were generally preferred over single arches. This preference for multiple inflections is repeated in the truss preference models, later. In terms of particular design concepts that were acceptable or preferred by both the Public and the Sec. 106 consulting parties, there were some areas of potential convergence. Generally, light colored arches of low complexity were tolerated by all participants, and especially in combination with single or twin “H” arches, or twin “A” or “Modified A” arches. Single baskethandle arches were not as preferred under the same circumstances.
5.3 Truss Preferences

Truss concepts yielded the greatest difference between Public and Sec. 106 preferences. Here, trusses with two or more haunches and low enclosure yielded the highest average preference surfaces of any truss concepts. Although the Public surface shows a distinctly low preference at moderate complexity and dark color, overall the preference surface is slightly above average (dark blue). The Sec. 106 surface shows high to very high preference for the entire surface, with a peak near the location of Truss 6, a near copy of the form of the existing Milton Madison bridge.
Trusses with no haunches and high enclosure were, at best, tolerated, and, where colors became darker, similarly unpreferred by both the Public and Sec. 106 groups. It is possible, but not likely, that lighter colors would raise preference for this family of designs up to average.
Trusses with no haunches and low enclosure effect could at least expect lukewarm to slightly negative responses from both the Public and Sec. 106 participants. Color and complexity differences would have little effect on preference.
Adding one haunch to the trusses with low enclosure would uniformly raise preference to above average. Other modifications would have little effect.
When the enclosure effect is heightened with one-haunch trusses, certain portions of the preference surface begin to degrade to average. The Public group is slightly more sensitive to darker colors, while the Sec. 106 is slightly more sensitive to lowered complexity.
In this alternative slice through the Knowledge Base, the positive effect of increasing the number of haunches can be more clearly seen. For moderately complex trusses with low enclosure effect, both Public and Sec. 106 surfaces show higher preference (even very high preference) towards the right hand (more haunches) portion of the surface.

### 5.4 Trusses Summary

While trusses were, overall, the least preferred structures tested, and the greatest differences between Public and Sec. 106 were measured here, there are nonetheless productive areas of the design envelope that are promising. Truss designs are more preferred by all concerned when they have:

- More haunches
- Taller structure
- Moderate complexity
- Color preference tends toward darker for Sec. 106, lighter for Public.
5.5 Cable Stay Preferences

Cable stays exhibited the highest overall preferences by both the Public and Sec. 106 groups. At worst, they differed on which of the “A”-shaped twin tower arrangements were ‘Very High’ vs. merely ‘High.’ The model indicates that even dark colors would not lower preference below High. This is consistent with the color variations only being applied to the deck, the less prominent portion of the structure.
Twin cable stay towers that are somewhat inclined yield overall preference that is somewhat lower than “A” shapes, and almost identical for the two groups. Again, color and cable complexity have little effect on preference.
Cable stay designs with “H” shaped towers yield a slightly lower overall preference than the modified shape towers, with negative tendencies toward darker colors except in the case of Sec. 106 participants who strongly preferred the dark colored, highly complex “H” shaped twin towers of CS1. This difference with the Public in preference is the largest single difference between the two groups across all the samples. It is possible that the horizontal crossbar feature of this design is suggestive of the horizontal members of truss haunches, also highly preferred by Sec. 106 members. However, we have no firm data to support that idea.

5.6 Cable Stay Summary
As mentioned before, only twin tower cable stays were tested in this project, and color variation was only allowed on the deck. Thus the range of visual variability was more restricted for cable stays. Nonetheless, this group was overall the most preferred design category of the three structure types. Within that, “A” shaped towers were
clearly more preferred by Public and Sec. 106 alike. Moderate or "H" shaped towers were generally well received, but dipped down to the Average category of preference under certain circumstances. Light to Moderate Color values were generally helpful, although not a strong influence either way with the exception of Sec. 106 preference for dark, highly complex "H" shaped cable stay designs. Cable complexity was generally unimportant, although one comment was recorded against harped cable arrangements. Again, our data indicates no particular direction regarding preference for cable arrangements.

5.7 Overall Preference Summary

An important goal of this preference project was to understand the extent and nature of difference in preferences for subgroups of a single community. As the preceding work demonstrates, this was accomplished in great detail. Because of that level of detail, we are able to have some confidence in the information we can provide to the design team. We have gone far beyond the bridge aesthetics literature that suggests arches are more preferred than other structural types, or that light tans and greys are the best colors, or that bridges should be visually attractive/harmonious/balanced/etc/etc/etc. This report contains specific data linked to the citizens of Milton and Madison that reflects their specific preferences for their specific bridge, in terms that can be used by designers to guide their decision-making process. The summary observations are:

- The average preference scores were highest for cable-stay designs, although the variability across the participants was the highest. That is to say, all of the cable stay designs were generally preferred, but none of them, indeed none of the 18 concepts, was a single, clear ‘winner.’
- While the public and Sec. 106 average scores were often significantly different in value, they both tended to prefer, or not prefer, the same types of designs, but with greater or lesser intensity. Sec. 106 participant scores absolute scores tended to be higher and lower than those of the general public.
- Low to moderate complexity plus light color arches were preferred.
- Twin arches were generally preferred to single arches, and light arches were preferred to dark.
- Single or twin "H" arches, or twin "A" or "Mod" arches with light color and low complexity could be considered if needed for other, non-aesthetic reasons.
- Truss concepts were generally less preferred than arches or cable stays, with the exception of concepts that invoked the existing bridge in terms of shape and style.
- Lighter colors and multiple haunches were most preferred for trusses.
- Those trusses that were most preferred by Sec. 106 were also most preferred by the Public.
- "A" Shaped cable stay towers were preferred to Moderately Inclines, which were slightly preferred to “H” shapes.
- Complexity of cable arrangement was not an important factor in cable stays.
- Deck color was of only minor significance in cable stays.
5.8 **Public Satisfaction With SPI Process**

While we were able to gather a great deal of useful information from the public, it is always a possibility that the public feels they have not been treated fairly or have not been given an adequate chance to express their views. This is especially a concern where the public’s primary (although not only) means of expressing opinions is through the use of a keypad. Thus, our last question at the meeting was to invite the participants to evaluate their satisfaction with the overall process that evening. As the chart demonstrates, satisfaction with the process was very good.

**Rate the Scoring Process**

1. Very Unsatisfactory
2. Unsatisfactory
3. Somewhat Unsatisfactory
4. Slightly Unsatisfactory
5. Neutral
6. Slightly Satisfactory
7. Somewhat Satisfactory
8. Satisfactory
9. Very Satisfactory

![Bar Chart of All Respondents: Rate Your Satisfaction With This Process](image-url)

Figure 33: Bar Chart of All Respondents: Rate Your Satisfaction With This Process
6. References


