Using Full Factorial Analysis to Enhance Water Quality Monitoring Programs

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Outline

- Introduction
- n-Orthogonal Sampling Model
- Case Study – Illinois River; Peoria, Illinois
Full Factorial Regression Analysis (FFRA)

- Use when conclusions must be drawn from relatively small sample set.
- Full Factorial approach uses one data point multiple times to evaluate changes in water quality using paired comparisons.
- Regression Analysis creates a regression model to overcome problems such as missing samples.
- In FFRA, samples are collected in n-orthogonal dimensions (influencing factors) each with 2 or more levels.
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- n-Orthogonal Sampling Design
- Case Study – Illinois River; Peoria, Illinois
Orthogonal Design

- Orthogonal **Dimension** (aka. Influencing Factor)
  - Depth of Sample
  - Location of Sample
- Dimension **Level**
  - Depth of Sample = Shallow, Deep, Mid-depth
  - Location of Sample = Near Shore, Navigation Channel, Far Shore
- Dimensions are independent of each other
  - Time and Plume Travel – NOT INDEPENDENT
- Dimensions can be Categorical or Continuous
Example Orthogonal Design

3 Dimensions (ie. Influencing Factors) each with 2 Levels

- **Weather**
  - Wet
  - Dry

- **Location from Source**
  - Upstream
  - Downstream

- **Sample Depth**
  - Shallow
  - Deep
Orthogonal Design

Orthogonal Design with 3 **Dimensions** (factors), each with 2 **Levels**

Utilizing each water quality sample in multiple paired comparisons gives technique its strength.

- **Shallow**
- **Dry weather**
- **Downstream**
How Does Full Factorial Analysis Work with Orthogonal Design?

- Change in water quality is computed by averaging the change in pairs of samples.

Depth (Shallow – Deep)  
Location (Upstream - Downstream)  
Weather (Wet-Dry)
Orthogonal Design and FFRA

Average **Location** Effect = \( \frac{(y_2 - y_1) + (y_4 - y_3) + (y_6 - y_5) + (y_8 - y_7)}{4} \)

Average **Weather** Effect = \( \frac{(y_5 - y_1) + (y_6 - y_2) + (y_7 - y_3) + (y_8 - y_4)}{4} \)

Average **Depth** Effect = \( \frac{(y_3 - y_1) + (y_4 - y_2) + (y_7 - y_5) + (y_8 - y_6)}{4} \)

- 2 Sampling Rounds = 8 samples
- 8 Samples = 12 paired comparisons
- W/o FFRA, it would take 24 samples to make the same comparisons

Full Factorial Analysis can assess factor Interactions as well!
How Does the Analysis Work?

JMP 6.0 from SAS Institute, Cary, NC

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
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<tbody>
<tr>
<td>Model</td>
<td>8</td>
<td>38.854781</td>
<td>4.85685</td>
<td>18.7473</td>
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<td>Error</td>
<td>154</td>
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<td>0.25907</td>
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<tr>
<td>C. Total</td>
<td>162</td>
<td>78.751342</td>
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</tr>
</tbody>
</table>

E. coli (Log CFU/100ml) Actual

- Dimension test using ANOVA
- Level tests using several ad-hoc pair wise comparisons (ex. Tukey-HSD)
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Illinois River; Peoria, Illinois
Peoria, Illinois

- City is served by combined and separate storm sewers.
- City discharges at 16 permitted CSO outfalls.
- Water levels in Illinois River maintained for navigation.
- Symbiont and other members of the MACTEC team conducted water quality study in the Illinois River to evaluate CSO impacts.
Water Quality Study

- Developed specific set of questions
- Identified **Dimensions** and **Levels**
- Monitoring network of 20 sampling locations
- Samples collected nearly random and analyzed for selected constituents of concern
City of East Peoria, Illinois

Longitudinal Transect Number

T1 T2 T3 T4 T5

Sample Location

1 5 9 13 17

Far Shore

Mid-Channel (MC)

2 6 10 14 18

Navigation Channel

3 7 11 15 19

Between NS and MC

Near Shore (NS)

4 8 12 16 20

Inputs to the Illinois River

CSOs 001, 003, 006A, 006B, 007A, and 008

CSOs 020, 009, 010, 011, 013, and 014

CSOs 016, 017, 018, 019 and GPSD Outfall

City of Peoria, Illinois

Other Dimensions

1. Weather
2. River Stage
### Example Question and Model

#### Question
Does water quality in the Illinois River generally degrade during wet weather?

#### Model Dimensions

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Levels</th>
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</thead>
<tbody>
<tr>
<td>Longitudinal Transect Number</td>
<td>T1, T2, T3, T4, T5</td>
</tr>
<tr>
<td>Lateral Transect</td>
<td>Near Shore, Between Near Shore and Mid Channel, Mid Channel, Far Shore</td>
</tr>
<tr>
<td>Weather</td>
<td>Wet Weather, Dry Weather</td>
</tr>
<tr>
<td>River Stage</td>
<td>Normal Pool, Above Normal Pool</td>
</tr>
</tbody>
</table>
Multiple Models

- Single model was not sufficient to answer all project questions
- Certain effect levels had to be combined

<table>
<thead>
<tr>
<th>Question</th>
<th>Model Dimensions</th>
<th>Dimension Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does water quality degrade in the Illinois River during a CSO event as it flows through the City of Peoria?</td>
<td>Time</td>
<td>Pre-CSO, During CSO, River Flushed</td>
</tr>
<tr>
<td></td>
<td>General Longitudinal Location</td>
<td>Upstream, CSO Warning Area</td>
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<tr>
<td></td>
<td>River Stage</td>
<td>Normal Pool, Above Normal Pool</td>
</tr>
<tr>
<td></td>
<td>General Lateral Position</td>
<td>Near Shore, River</td>
</tr>
</tbody>
</table>

- Combining **Levels** allowed for other questions to be answered
Water quality degrades in the Illinois River during a CSO event, in both the downstream areas impacted by Peoria CSOs and the upstream area not impacted by Peoria CSOs. During dry and wet weather, water quality was worse in the CSO Warning Area (Transects 2 through 5 combined) as compared to upstream (Transect 1). Etc.
Lessons Learned

- Before starting water quality monitoring project, develop **SPECIFIC** questions to answer
- Design the monitoring network and analysis to answer these questions
- Some questions cannot be answered by a single model
Acknowledgements

- MACTEC Team Members
- Jane Gerdes, Gene Hewitt – City of Peoria
- Dale Howard, Bob Hawes – City of Rock Island
Questions?