The Application of BIM and IPD in Public Design and Construction

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BIM and IPD in Public Works

- Introduction
- Background
- Research Objectives
- Research Methodology
- Research Process & Result
- Case Study
- Conclusion
Introduction

Building Information Modeling (BIM)

– “An intelligent simulation of architecture”

– Key Characteristics:
  1. Digital
  2. Spatial (3D)
  3. Measurable
  4. Comprehensive
  5. Accessible
  6. Durable
BIM Functions

- Design Visualization
- Schedule Visualization
- Design Validation: Clash Detection, Light Analysis, Temperature Distribution
- Quantity Take-Off & Cost Estimating
- Site Layout & Logistics (Site Safety)
- Material Tracking
- Facility Operation & Management
- Sustainability Planning
Integrated Project Delivery (IPD)

- Collaborative, team-based process
- Change adversarial relationship
- Guiding principles:

<table>
<thead>
<tr>
<th>Mutual respect and trust</th>
<th>Intensified planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mutual benefit and rewards</td>
<td>Appropriate technology</td>
</tr>
<tr>
<td>Open communication</td>
<td>Financial transparency</td>
</tr>
<tr>
<td>Early involvement of key</td>
<td>Collaborative innovation and</td>
</tr>
<tr>
<td>participants</td>
<td>decision making</td>
</tr>
<tr>
<td>Early goal definition</td>
<td>Organization and leadership</td>
</tr>
</tbody>
</table>
IPD Definition

- A project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste and maximize efficiency through all phases of design, fabrication and construction (AIAA Guide, 2007).
BIM & IPD are Complimentary

- IPD involves communication, collaboration, coordination, risk and reward sharing
- BIM provides a common platform for communication, collaboration and problem solving
Motivation for BIM & IPD

Waste & Lack of Productivity

- 57% of construction resources are wasted
  - 12% of resources in manufacturing are wasted
  - Construction productivity has decreased since 1964
  - All other non-farm industries have increased by ≈200%
BIM & IPD Current Implementation

- Private sector applying BIM & IPD more
- Public restricted by
  - Procurement options
    - Competitive bidding statutes require award of construction contracts to the lowest responsive, responsible bidder
    - Design-Bid-Build
  - Implementation Barriers
    - Culture barrier
    - Financial barrier
Can BIM & IPD be applied to the Public Sector in NYC?

NYC Police Academy
Research Objectives

• Identify the Concept for Public Sector Implement BIM & IPD
  − Outline existing constraints
  − Propose an implementation model within constraints

• Identify the Advantages and Disadvantages Associated with Implementation
  − Benefits: such as cost saving, change orders reduction
  − Disadvantages of the implementation

• Recommendations for Public Entities
Research Methodology

1. Investigation of the Public Contract Regulations and Propose Alternative Model
   • Comparison analysis of private sector and public sector
   • Feasibility analysis for the alternative model

2. Data Collection and Change Order Analysis
   • Data collected from DDC and find a measurement variable
   • Quantify change order variables in order to measure the cost performance of new model
3. Statistical Analysis of Model Benefits

- **Change Order Forecast Model**
  - Bayesian Networks inferences
  - Forecast change orders given BIM & IPD information
  - Revise belief by Bayes’ Theorem

- **BIM & IPD Efficiency Evaluation**
  - Monte Carlo simulation for BIM & IPD efficiency
  - Identify BIM & IPD maturity level

- **Contingency Calculation**
  - Ensure a cost under run (Public Owners cannot share risk)
  - Estimate proper contingency
  - Identify the confidence level that contingency encourage collaboration and innovation
Research Work Flow

1. Constraints for Public Agency Implement BIM and IPD
2. Propose IDDB Model
3. Determine BIM and IPD Efficiency Level
4. Change Order (C.O.) Categorize (DE, DO, FC)
5. Develop Prediction BN Model
6. Analyze and Verify Model
   - Good
   - Bad
7. Model Application
8. C. O. Outcomes (Price, %, Freq.)
9. Cost Saving in IDDB Compared with DBB
10. Develop Algorithm to Compute Contingency
11. Recommendations on Public Agency Implement IDDB
Propose An Alternative Model

- Big Difference Between Public and Private Sectors
- Contractual Freedom
  - Private owner can assemble project team and choose their desired project delivery process
  - Public has to follow a series of laws and regulations
Legal Restrictions in NYC Public Works

• Government Public Law _“Brooks Act”_
  – Contracts for architectural and engineering services on the basis of demonstrated competence and qualification

• NY State General Municipal Law (GML) § 103
• NY City Charter Chapter 13
• NY State Public Construction Bidding Laws (PCBL)
• NY City Procurement Policy Board (PPB) Rules
  – Construction work be awarded to the lowest responsible bidder based on open competitive bidding
  – Traditional Design-Bid-Build (DBB)
Integrated DBB

Public Statute
- D-B-B
- Lowest Responsive, Responsible Bidder

Collaboration
- BIM Functions
- IPD Principles

Integrated DBB
Integrated DBB (IDBB)

IDBB is a revolutionary project delivery method that employs the procurement of construction services by traditional design-bid-build process but includes the requirement to employ Building Information Modeling (BIM) and most of the principles of Integrated Project Delivery (IPD).
Integrated DBB (IDBB) Principles

- Mutual Trust and Respect
- Mutual Benefits and Rewards (not Risk)
- Integrated BIM Technology
- Collaborative Decision Making
- Open Communication & Certain Level Transparency
- Design Package Early Release
- **Project Team Co-Location**
- **Owner’s Leadership**
- **Optional Early Contractor Involvement** (FAR § 52.216-17)
Timeline Comparison of IDBB, DB and DBB
Cost Benefit Analysis of IDBB

- **Change Order (CO) as measurement variable**
  - Have significant effect on both design and construction productivity
  - Act as performance measurement by many researchers
- **BIM & IPD Reduce Change Orders**

<table>
<thead>
<tr>
<th>Contract Value $$</th>
<th>Change Orders $$</th>
<th>Design Error</th>
<th>Design Omission</th>
<th>Field Condition</th>
<th>IDBB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>
BIM & IPD Efficiency Evaluation

- The extent of the ability and the performance of BIM functions & IPD principles, value between 0 to 1
  - BIM functions used by variety parties in different project phases
  - Project team evaluate each factor
  - Fitted Distribution: Beta, Triangular Distribution
  - Monte Carlo Simulation
Bayesian Networks Inference

Bayesian Statistics vs. Frequentist Statistics
- Frequentist: consider parameters as fixed constant
- Bayesian: Parameters are random variables with probability statement

Bayesian Networks (BN) Build Cause and Effect Relationship between IDBB and COs
- Both qualitative knowledge and quantitative knowledge
- Revise CO’s outcomes given BIM & IPD
- Tool: Bayes’ theorem

\[ P(A | B) = \frac{P(A \cap B)}{P(B)} \]
Bayesian Network Inference Process

- $X_1 \sim \text{RN}: \text{Project IDBB Implementation}$
- $X_2 \sim (0-1): \text{BIM Efficiency}$
- $X_3 \sim (0-1): \text{IPD Efficiency}$
- $X_4 \sim (0-1): \text{Change Order (DE)}$
- $X_5 \sim \text{RN}: \text{Cost Saving}$

<table>
<thead>
<tr>
<th>BIM Efficiency (BE)</th>
<th>Good (1)</th>
<th>Bad (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPD Efficiency (IE)</td>
<td>Good (1)</td>
<td>Bad (0)</td>
</tr>
<tr>
<td></td>
<td>Good (1)</td>
<td>Bad (0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Error (DE)</td>
<td>Avoided (A) &amp; 1 &amp; 0.75 &amp; 0.42 &amp; 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not Avoided (NA) &amp; 0 &amp; 0.25 &amp; 0.58 &amp; 1</td>
<td></td>
</tr>
</tbody>
</table>
with BIM Efficiency (BE) is $X_1$
IPD Efficiency (IE) is $X_2$

<table>
<thead>
<tr>
<th>BIM Efficiency (BE)</th>
<th>good ($X_1$)</th>
<th>bad (1-$X_1$)</th>
<th>IPD Efficiency (IE)</th>
<th>good ($X_2$)</th>
<th>bad (1-$X_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoided (A)</td>
<td>$X_1<em>X_2</em>1$</td>
<td>$X_1*(1-X_2)*0.75$</td>
<td>Avoided (A)</td>
<td>$X_1<em>X_2</em>0$</td>
<td>$X_1*(1-X_2)*0.25$</td>
</tr>
<tr>
<td>Not Avoided (NA)</td>
<td>$X_1<em>X_2</em>0$</td>
<td>$X_1*(1-X_2)*0.25$</td>
<td>Not Avoided (NA)</td>
<td>$X_1<em>X_2</em>0$</td>
<td>$X_1*(1-X_2)*0.25$</td>
</tr>
</tbody>
</table>

$P(DE=A)=0.75*X_1+0.42*X_2-0.17*X_1*X_2$
$P(DE=NA)=1-0.75*X_1-0.42*X_2+0.17*X_1*X_2$

- $(0.75*X_1+0.42*X_2 -0.17*X_1*X_2)$ probability DE being avoided by BIM & IPD
- $(1-0.75*X_1-0.42*X_2+0.17*X_1*X_2)$ probability DE will not being avoided
- E.g:$X_1=0.8$, $X_2=0.7$, $P(DE=A)=0.79$ (79% chance DE avoid)
- $P(DE=NA)=0.21$ (21% chance DE not avoid)
Contingency Calculation

- No Rational Method for Contingency
  - Rule of Thumb
  - Percentage of contract value
  - Lack of statistics analysis support
- Develop Algorithm for Contingency
  - Too much or less damage collaboration
  - Public owner cannot share risk
- Contingency Calculation Method
  - Change Orders’ random characteristics
    - Occurrence follow a Poisson distribution
      \[ P[X = x] = \frac{e^{(\lambda T)} (\lambda T)^x}{x!} \quad x = 0, 1, 2, \ldots \]
Contingency Calculation Method

- Total COs Cost

\[ C_T = \sum_{i=1}^{n} C_i \]

- From historical data, CO has an average amount and variance, assume each CO share same mean and variance and \( n \) is large,

- CT follow a Normal distribution (CLT)

\[ C_T \sim N \left( \sum_{i=1}^{n} \mu_{C_i}, \sum_{i=1}^{n} \sigma_{C_i}^2 \right) \]

- Set up contingency \( \alpha \), cost under-run probability can be calculated

\[
P[C_T \leq a] = \sum_{x=0}^{\infty} P[C_T \leq a | X = x] P[X = x]
\]

\[
= \sum_{x=0}^{\infty} \left[ \int_{-\infty}^{a} \frac{1}{\sqrt{2\pi} \sqrt{\sum_{i=1}^{n} \sigma_{C_i}^2}} e^{-\frac{1}{2} \left( \frac{y - \sum_{i=1}^{n} \mu_{C_i}}{\sqrt{\sum_{i=1}^{n} \sigma_{C_i}^2}} \right)^2} dy \right] \Phi \left( \frac{a - \lambda T}{\lambda T} \right)
\]
Contingency Calculation Tool

### Historical Change Order Information

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<tr>
<th>Probability</th>
<th>0.971</th>
<th>0.972</th>
<th>0.973</th>
<th>0.974</th>
<th>0.975</th>
<th>0.976</th>
<th>0.977</th>
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<th>0.979</th>
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<td>0.04</td>
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<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
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### Poisson Distribution

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<th>X</th>
<th>Density</th>
<th>Cumulative</th>
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<tr>
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<td>0.001000</td>
</tr>
<tr>
<td>1</td>
<td>0.002000</td>
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<td>2</td>
<td>0.004000</td>
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<td>3</td>
<td>0.008000</td>
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<td>4</td>
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<td>5</td>
<td>0.032000</td>
<td>0.064000</td>
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<tr>
<td>6</td>
<td>0.064000</td>
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<td>0.128000</td>
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<td>8</td>
<td>0.256000</td>
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</tr>
<tr>
<td>9</td>
<td>0.512000</td>
<td>1.024000</td>
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### CO Occurrence

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<tr>
<th>Confidence</th>
<th>0.0</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
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</thead>
<tbody>
<tr>
<td>Probability</td>
<td>0.05</td>
<td>0.10</td>
<td>0.15</td>
<td>0.20</td>
<td>0.25</td>
<td>0.30</td>
<td>0.35</td>
<td>0.40</td>
<td>0.45</td>
<td>0.50</td>
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### Confidence Under run Probability

<table>
<thead>
<tr>
<th>Probability</th>
<th>0.05</th>
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<th>0.15</th>
<th>0.20</th>
<th>0.25</th>
<th>0.30</th>
<th>0.35</th>
<th>0.40</th>
<th>0.45</th>
<th>0.50</th>
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<tbody>
<tr>
<td>Confidence</td>
<td>0.50</td>
<td>0.45</td>
<td>0.40</td>
<td>0.35</td>
<td>0.30</td>
<td>0.25</td>
<td>0.20</td>
<td>0.15</td>
<td>0.10</td>
<td>0.05</td>
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### Cost Under run Probability

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<th>0.15</th>
<th>0.20</th>
<th>0.25</th>
<th>0.30</th>
<th>0.35</th>
<th>0.40</th>
<th>0.45</th>
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<tbody>
<tr>
<td>Confidence</td>
<td>0.50</td>
<td>0.45</td>
<td>0.40</td>
<td>0.35</td>
<td>0.30</td>
<td>0.25</td>
<td>0.20</td>
<td>0.15</td>
<td>0.10</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Case Study: A Controlled Experiment

Systems Engineering Facility III (SMEFI III)

- Solicitation
  - NYC DDC Public IDBB procurement contract
  - BIM requirement
  - As many as possible IPD principles encouraged

- Joint Effort and Support by:
  - NYC DDC (Public Owner)
  - W.J. Northridge Construction Corp. (Contractor)
  - Group PMX (Represent A/E)
Experiment Strategy

• Phase I: BIM functionality and Bid Preparation
  – General Contractors Role
  – BIM Functions Performance
    • Quantity take off and Cost estimation by using BIM
    • Create base schedule and alternative schedules
    • 4D simulation demonstrates construction concepts
    • Animation for site logistics analysis
  – Journal Report

• Phase II: Time-Cost Trade-off Analysis
  – General Contractors Role
  – BIM Platform for Coordination
    • Time-cost trade-off analysis among three schedules: 565d->455d->365d
    • 4D simulation the time-cost trade-off decisions and strategies
Experiment Strategy

• **Phase 3: IPD Problem Solving**
  – IPD Team
    • Public owner (Advisor: DDC)
    • A/E designer (Advisor: Group PMX)
    • Contractor (Advisor: W.J. Northridge Construction)
    • Subcontractor (Advisor: W.J. Northridge)
  – Issues Packages I-III
  – Weekly Presentation
    • Solutions
    • IPD principles
    • Collaboration strategy

<table>
<thead>
<tr>
<th>Issue package I</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule Issue</td>
<td>Shop drawing submission has 2 weeks late.</td>
</tr>
<tr>
<td>Value Engineering</td>
<td>Foundation piles change from 12”ϕ to 10-3/4”ϕ.</td>
</tr>
<tr>
<td>Quality Control</td>
<td>Pile driving mistakes happen during construction.</td>
</tr>
<tr>
<td>Issue package II</td>
<td></td>
</tr>
<tr>
<td>Weather Issue</td>
<td>Heavy rain affects the construction process for 2 weeks.</td>
</tr>
<tr>
<td>Payment Issue</td>
<td>Owner delayed payment to the contractor for 60 days.</td>
</tr>
<tr>
<td>Quality Control</td>
<td>Efflorescence happens in the exterior brick wall.</td>
</tr>
<tr>
<td>Issue package III</td>
<td></td>
</tr>
<tr>
<td>Clash Detection</td>
<td>HVAC and Structure clash is found in third floor.</td>
</tr>
<tr>
<td>Clash Detection</td>
<td>HVAC duct conflict with Steel column with criteria 2”.</td>
</tr>
<tr>
<td>Scope Change</td>
<td>Owner change scope by adding bridge linking to an existing building.</td>
</tr>
</tbody>
</table>
### BIM Efficiency Evaluation Final Results

#### BIM Efficiency Evaluation

<table>
<thead>
<tr>
<th>Technology</th>
<th>Generated</th>
<th>Min</th>
<th>Most Likely</th>
<th>Max</th>
</tr>
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<tbody>
<tr>
<td>BIM_T_1_Visualization</td>
<td>0.80</td>
<td>0.5</td>
<td>0.9</td>
<td>1</td>
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<tr>
<td>BIM_T_2_Clash Detection</td>
<td>0.80</td>
<td>0.5</td>
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<tr>
<td>BIM_T_3_Facility Management</td>
<td>0.23</td>
<td>0.1</td>
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<td>0.3</td>
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<tr>
<td>BIM_T_4_Quantity Take off</td>
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<td>0.7</td>
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<tr>
<td>BIM_T_5_Cost Estimation</td>
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<tr>
<td>BIM_T_6_4D Simulation</td>
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<td>BIM_T_7_Sustainability</td>
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<tr>
<td>BIM_T_8_Others</td>
<td>0.13</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
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Generated Technology Weights: 0.58

<table>
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<tr>
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<th>Most Likely</th>
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<tbody>
<tr>
<td>BIM_P_1_Leadership</td>
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<td>BIM_P_2_Products&amp;Services</td>
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<td>BIM_P_4_Collaboration</td>
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</table>

Generated Process Weights: 0.59

#### Final Score

- **Final Score**: 0.587
- **Maturity Level**: 3

#### Maturity Level:
- 1: Initial → 2: Defined → 3: Managed → 4: Integrated → 5: Optimized

![BIM Efficiency Assessment Chart](chart.png)
### IPD Efficiency Evaluation Results

#### IPD Efficiency Evaluation

<table>
<thead>
<tr>
<th>Leadership</th>
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<th>Most Likely</th>
<th>Max</th>
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#### BIM

<table>
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<tr>
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<th>Generated Leadership Weights</th>
<th>Min</th>
<th>Most Likely</th>
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#### Process

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<tr>
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<th>Generated BIM Weights</th>
<th>Min</th>
<th>Most Likely</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPD_P_1_Early Involvement</td>
<td>0.33</td>
<td>0.1</td>
<td>0.4</td>
<td>0.5</td>
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<tr>
<td>IPD_P_2_Shared Risk &amp; Reward</td>
<td>0.70</td>
<td>0.4</td>
<td>0.8</td>
<td>0.9</td>
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<tr>
<td>IPD_P_3_Multi-Party Contract</td>
<td>0.60</td>
<td>0.3</td>
<td>0.7</td>
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<tr>
<td>IPD_P_4_Collab. Decision-Making</td>
<td>0.53</td>
<td>0.3</td>
<td>0.6</td>
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<tr>
<td>IPD_P_5_Liability Waivers</td>
<td>0.50</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
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<tr>
<td>IPD_P_6_Jointly Developed Goal</td>
<td>0.47</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**Final Score**: 0.491
**Maturity Level**: 3

- Maturity Level: Initial → Defined → Managed → Integrated → Optimized
Bayesian Networks Inference Results

- Change Orders avoided by BIM & IPD
  - 67% Design Error
  - 66% Design Omission
  - 49% Field Condition

- Predicting Change Orders
  Percentage in contract value is 4.59%

<table>
<thead>
<tr>
<th></th>
<th>Non-BIM/IPD</th>
<th>SMEFIII</th>
<th>Full BIM/IPD</th>
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</thead>
<tbody>
<tr>
<td>BIM Efficiency</td>
<td>0</td>
<td>0.58</td>
<td>1</td>
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<tr>
<td>IPD Efficiency</td>
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<td>0.49</td>
<td>1</td>
</tr>
<tr>
<td>DE Avoidability</td>
<td>0%</td>
<td>67%</td>
<td>100%</td>
</tr>
<tr>
<td>DO Avoidability</td>
<td>0%</td>
<td>66%</td>
<td>100%</td>
</tr>
<tr>
<td>FC Avoidability</td>
<td>0%</td>
<td>49%</td>
<td>85%</td>
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<tr>
<td>CO_ # (Mean)</td>
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<td>8.36</td>
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<td>CO_ # (STD)</td>
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<td>CO_ $ (Mean)</td>
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<td>$168,000</td>
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<tr>
<td>CO_ $ (STD)</td>
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<td>$160,624</td>
<td>$15,150</td>
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<td>CO_ % (Mean)</td>
<td>9.62%</td>
<td>4.59%</td>
<td>0.48%</td>
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<tr>
<td>CO_ % (STD)</td>
<td>3.97%</td>
<td>4.55%</td>
<td>0.25%</td>
</tr>
</tbody>
</table>
Contingency Calculation

• Average CO Occurrence: \( \lambda = 8.36 \)
• Each CO Cost Percentage in Contract value
  – \textit{Mean} \( \mu_c = \frac{4.59\%}{8.36} \)
  
  – \textit{Var.} \( \sigma_i^2 = \frac{(4.55\%)^2}{8.36} \)
• Use contingency tool
  – 90% confidence @ 8% Contingency
  – 80% confidence @ 7% contingency
  – 50% confidence @ 4.5% contingency
• Encourage collaboration
  – Prevent a cost overrun
  – Ensure a saving sharing
Case Study Summary

- IDBB Involved some BIM Functions & IPD Principles
  - BIM Level 3 Managed at 0.587
    - Visualization, Clash Detection, Quantity Take-off, Cost Estimation, 4D simulation, Animation, Site Logistics
  - IPD Level 3 Managed at 0.491
    - Co-Location, Mutual Trust and Respect, Mutual Benefits, Open Communication, Certain Transparency, Collaborative Decision Making

- Change Order Reduction and Cost Saving
  - 67% DE, 66% DO and 49% FC are reduced
  - 90% confidence with contingency level @ 8%

- Issues associated with Experiment Project
  - Some teams fail when changes cost overrun the contingency
  - Project owner lacks leadership
Conclusion

- **IDBB provides public owners an alternative model to implement BIM & IPD**
  - **Advantages of IDBB**
    - Reduce change orders and save cost
    - Shorten schedule and save time
    - Encourage better collaboration and innovation
  - **Further Requirement of IDBB**
    - Require better leadership
    - Need culture training
    - Require training for BIM use in construction management

- **Proposed statistics analysis model helps public owners**
  - Evaluate BIM & IPD efficiency
  - Forecast change orders
  - Calculate proper contingency to prevent a cost overrun

- **IDBB can be a successful project delivery method with owner’s appropriate training & leadership**
Thank you!

Questions?