Operational Techniques for Facilitating Traceability at a Grain Elevator

Maitri Thakur
Dr. Charles R. Hurburgh, Jr.
Department of Agricultural and Biosystems Engineering
Department of Industrial and Manufacturing Systems Engineering
Iowa State University, Ames, IA

Agricultural and Food Traceability Conference
Des Moines, Iowa
June 9-11, 2009
Two-part presentation

- Data modeling for internal traceability
- Mathematical model for traceability optimization
Traceability Regulations

- Several Food Safety and Traceability Regulations exist in different countries
  - EU’s General Food Law
  - Bioterrorism Act of 2002
  - CanTrace

- Bioterrorism Act of 2002
  - Self registration
  - Maintain records to identify immediate previous sources and subsequent recipients of food

- Timeliness
  - In case of an outbreak, FDA requires that a company produce requested records within a 24 hour time period.
Traceability terminology

- Internal Traceability and Chain Traceability
  - Internal traceability – keeping track of all physical entities and their transformations that take place within an enterprise
  - Chain traceability – Information sharing between different enterprises in a supply chain

- Tracking and Tracing
  - Tracking a physical entity until the point of consumption by end user
  - Tracing the origin of a physical entity
Typical Grain Supply Chain
Typical Grain Lot Blending Scenario

*Bin- Storage bin, each bin is considered as one lot
Contaminated Lot Consequences

*Bin- Storage bin, each bin is considered as one lot
★ - Contaminated Lot
Grain Elevator Practices

- Internal grain movement often goes unrecorded
- Grain lots are divisible
- Lot identity is not maintained
Importance of Internal Traceability Systems

- Efficient supply chain traceability depends on both Internal and Chain Traceability Systems

- Effectiveness of information sharing and information retrieval depends on internal traceability systems as they link the process inputs and outputs
Objective

Develop a relational data model for internal traceability at a grain elevator to support both operational and analytical uses

Operational use – to support an enterprise’s business processes which includes short term decisions

Analytical use – to support an enterprise’s strategic decisions based on historical and integrated data
Relational Data Modeling

- Timeliness is key in food safety and traceability
- Need to establish relations between physical entities, their transformations and records of their suppliers and customers
- Relational data modeling techniques are used extensively for operational management programs
- Not common in agricultural industry
- We propose the use of relational data modeling as a solution for traceability
Methodology

- Entity-Relationship Model (E/RM) for modeling operational data

- E/RM differentiates between entities, relationships and attributes

- mE/RM is a specialization of E/RM and is suitable for conceptual modeling of OLAP (Online Analytical Processing) applications

- E/RM tested using the operational data from a grain elevator
Internal Traceability E/R Model

- **Objective**: To capture all information related to all incoming, internal and outgoing grain lot activities.
- **Triggers** used to store data in different tables according for different grain activities.

**General Form**

**Grain bin activity sub-types**
User Interface
User Interface

- All bin activities are recorded in the super-type table.
- Depending on the movement type, the corresponding data is added to the sub-type tables.
- Information retrieval is simplified by this design.
Performance Indicators

- Performance Indicators:
  - Tracking Efficiency: ____Track-able Quantity____
    Contaminated Quantity
  - Tracking Response Time – FDA requires a response time of less than 24 hours

- TRACKING(forward) – In case of a recall
- TRACING(backward) – In case of a food-safety related outbreak at the consumer end

- Tracing would always be followed by tracking
- First identify the source/s of contaminated material and then track the remainder of that material
Data

- Grain lot activity data was collected from Farmers Cooperative Company in Iowa

- Mock-recall data for years 2006-2007 was also available from Farmers Cooperative Company

- Based on this data, 20 mock recalls were conducted using the Internal Traceability ER Model
Results

Traceability – With and Without ER/M

- **WITHOUT INTERNAL TRACEABILITY**
  
  “Corn put into bin 4, blended with bin 5 and transferred to bin 101, loaded onto Tate & Lyle train on 6/30, 101 and 4 may still be contaminated”

- **WITH INTERNAL TRACEABILITY ER/M**

<table>
<thead>
<tr>
<th>ACTIVITY_DATE</th>
<th>CONTRACT_NUM</th>
<th>CUSTOMER_ID</th>
<th>BIN_NO</th>
<th>RAIL_ID</th>
<th>RAILCAR_ID</th>
<th>BUSHELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-MAR-08 10.25.00.000000 AM</td>
<td>C032208</td>
<td>C0001</td>
<td>2</td>
<td>10001</td>
<td>01</td>
<td>-5000</td>
</tr>
<tr>
<td>25-MAR-08 10.25.00.000000 AM</td>
<td>C032208</td>
<td>C0001</td>
<td>8</td>
<td>10001</td>
<td>01</td>
<td>-2000</td>
</tr>
<tr>
<td>28-APR-08 11.30.00.000000 AM</td>
<td>A042508</td>
<td>C0002</td>
<td>11</td>
<td>10001</td>
<td>11</td>
<td>-6000</td>
</tr>
<tr>
<td>28-MAR-08 10.25.00.000000 AM</td>
<td>C0040608</td>
<td>C0005</td>
<td>2</td>
<td>10003</td>
<td>12</td>
<td>-664</td>
</tr>
<tr>
<td>25-MAR-08 10.25.00.000000 AM</td>
<td>C032208</td>
<td>C0001</td>
<td>2</td>
<td>10001</td>
<td>01</td>
<td>-2000</td>
</tr>
<tr>
<td>25-MAR-08 10.25.00.000000 AM</td>
<td>C032208</td>
<td>C0001</td>
<td>8</td>
<td>10001</td>
<td>01</td>
<td>-5000</td>
</tr>
<tr>
<td>29-APR-08 09.25.00.000000 AM</td>
<td>G042808</td>
<td>C0003</td>
<td>9</td>
<td>10002</td>
<td>02</td>
<td>-5000</td>
</tr>
</tbody>
</table>
## Results

### Tracking and Tracing

### Sample Outputs

<table>
<thead>
<tr>
<th>ACTIVITY_DATE</th>
<th>CONTRACT_NUM</th>
<th>CUSTOMER_ID</th>
<th>BIN_NO</th>
<th>RAIL_ID</th>
<th>RAILCAR_ID</th>
<th>BUSHELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-MAR-08 10:25.00.000000 AM</td>
<td>C0322208</td>
<td>C0001</td>
<td>2</td>
<td>10001</td>
<td>01</td>
<td>-5000</td>
</tr>
<tr>
<td>25-MAR-08 10:25.00.000000 AM</td>
<td>C0322208</td>
<td>C0001</td>
<td>8</td>
<td>10001</td>
<td>01</td>
<td>-2000</td>
</tr>
<tr>
<td>26-APR-06 11:30.00.000000 AM</td>
<td>AO42506</td>
<td>C0002</td>
<td>11</td>
<td>10001</td>
<td>11</td>
<td>-6000</td>
</tr>
<tr>
<td>28-MAR-08 10:25.00.000000 AM</td>
<td>CG040808</td>
<td>C0005</td>
<td>2</td>
<td>10003</td>
<td>12</td>
<td>-564</td>
</tr>
<tr>
<td>25-MAR-08 10:25.00.000000 AM</td>
<td>C0322208</td>
<td>C0001</td>
<td>2</td>
<td>10001</td>
<td>01</td>
<td>-2000</td>
</tr>
<tr>
<td>25-MAR-08 10:25.00.000000 AM</td>
<td>C0322208</td>
<td>C0001</td>
<td>8</td>
<td>10001</td>
<td>01</td>
<td>-5000</td>
</tr>
<tr>
<td>29-APR-06 09:25.00.000000 AM</td>
<td>CO42608</td>
<td>C0003</td>
<td>9</td>
<td>10002</td>
<td>02</td>
<td>-5000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCALE_TICKET</th>
<th>PURCHASE_DATE</th>
<th>FARMER_NAME</th>
<th>BIN_NO</th>
<th>BUSHELS</th>
<th>ACTIVITY_DATE</th>
<th>CONTRACT_NUM</th>
<th>CUS_NAME</th>
<th>BIN_NO</th>
<th>SHIP_MODE</th>
<th>BUSHELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1011</td>
<td>15-MAR-08</td>
<td>Ron Penning</td>
<td>2</td>
<td>1564</td>
<td>26-MAR-08 10:25.00.000000 AM</td>
<td>CG040808</td>
<td>21st Century Grain Processing</td>
<td>2</td>
<td>R</td>
<td>-564</td>
</tr>
<tr>
<td>1010</td>
<td>15-MAR-08</td>
<td>Ron Penning</td>
<td>2</td>
<td>2200</td>
<td>26-MAR-08 10:25.00.000000 AM</td>
<td>CG040808</td>
<td>21st Century Grain Processing</td>
<td>2</td>
<td>R</td>
<td>-564</td>
</tr>
<tr>
<td>1019</td>
<td>16-MAR-08</td>
<td>John Smith</td>
<td>9</td>
<td>1698</td>
<td>02-MAY-08 02:25.00.000000 PM</td>
<td>CG040808</td>
<td>21st Century Grain Processing</td>
<td>9</td>
<td>T</td>
<td>-5000</td>
</tr>
<tr>
<td>1020</td>
<td>15-MAR-08</td>
<td>John Smith</td>
<td>9</td>
<td>2124</td>
<td>02-MAY-08 02:25.00.000000 PM</td>
<td>CG040808</td>
<td>21st Century Grain Processing</td>
<td>9</td>
<td>T</td>
<td>-5000</td>
</tr>
<tr>
<td>1019</td>
<td>15-MAR-08</td>
<td>John Smith</td>
<td>9</td>
<td>3200</td>
<td>02-MAY-08 02:25.00.000000 PM</td>
<td>CG040808</td>
<td>21st Century Grain Processing</td>
<td>9</td>
<td>T</td>
<td>-5000</td>
</tr>
<tr>
<td>1046</td>
<td>15-MAR-08</td>
<td>Pat Toreson</td>
<td>9</td>
<td>3025</td>
<td>02-MAY-08 02:25.00.000000 PM</td>
<td>CG040808</td>
<td>21st Century Grain Processing</td>
<td>9</td>
<td>T</td>
<td>-8000</td>
</tr>
<tr>
<td>1047</td>
<td>15-MAR-08</td>
<td>Pat Toreson</td>
<td>9</td>
<td>4205</td>
<td>02-MAY-08 02:25.00.000000 PM</td>
<td>CG040808</td>
<td>21st Century Grain Processing</td>
<td>9</td>
<td>T</td>
<td>-8000</td>
</tr>
<tr>
<td>1045</td>
<td>15-MAR-08</td>
<td>Pat Toreson</td>
<td>9</td>
<td>4850</td>
<td>02-MAY-08 02:25.00.000000 PM</td>
<td>CG040808</td>
<td>21st Century Grain Processing</td>
<td>9</td>
<td>T</td>
<td>-8000</td>
</tr>
</tbody>
</table>
## Results

### Performance Indicators

<table>
<thead>
<tr>
<th></th>
<th>Number of recalls</th>
<th>Mean Response Time (minutes)</th>
<th>Tracking Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without ER/M</td>
<td>41</td>
<td>804.0* (13.4 hours)</td>
<td>Uncertain</td>
</tr>
<tr>
<td>With ER/M</td>
<td>20</td>
<td>&lt;1.0</td>
<td>100%</td>
</tr>
</tbody>
</table>

- 5 recalls exceeded the 24 hour time limit. Max = 42 hours*
- One didn’t ID the sources*

Analytical Use

- Analytical tasks consist of derived measures to support strategic decisions.

- The internal traceability data model can be used to analyze grain handling practices to answer questions like:
  - What is the average quantity of grain moved from Location A to Location B in the year 2007?
  - Why is grain moved within company locations?
  - Why is grain moved from one bin to another?

- This information can be analyzed to define new handling procedures to optimize logistics costs and to minimize food safety risk.

- The data model needs to be implemented in order to gather enough information for analytical use.
Conclusions

- Use of a relational model for Internal Traceability drastically improves the response time and tracking efficiency.

- Response time is based on Query Processing time instead of the ability to follow and identify paper trail.

- However, a successful system is possible only when all the data is captured.

- No paper trail to follow.

- Tracking efficiency is independent of the quantity of contaminated material.
Next Steps

- Cost of implementation and maintenance to be considered

- Actual implementation in an elevator setting
Lot aggregation model to optimize traceability
Problem Statement

- Grain lots commingled/blended to meet customer specifications and to minimize discounts
- Lot identity not maintained
- High risk in terms of food safety due to blending
- Discounts applied but no premiums
Data (Farmers Coop, Iowa)

- Grain Quality and Quantity
  - Elevator - Number of grain storage bins, Volume (bushels) and Quality of grain in each bin
  - Customer Contract for outgoing shipments - Volume (bushels) and Quality of grain

- Grain Quality
  - Moisture (%)
  - Test Weight (lb/bu)
  - Damaged Material (%)
  - Foreign Material (%)
  - Contract specifications
    - Upper bounds for Moisture, DM, FM
    - Lower bound for Test Weight

- Discounts ($/bu) (>Moisture, <Test Weight, >Damaged Material , >Foreign Material)
Variables

- Which storage bins and amount of grain to be drawn for blending for a shipment
- Quality of blended lot
  - Moisture
  - Test Weight
  - Damaged Material
  - Foreign Material
- Total shipment discount
Mathematical Model

- Multi-objective mixed integer model is proposed

Objectives:

- Minimize Level of Lot Aggregation
  - Minimize number of storage bins used to blend grain for a shipment
- Minimize Discounts from Blending
Solution Techniques

- GLPK package for Linear Optimization
- Pareto Optimal Solutions
- Sensitivity Analysis
  - Changing constraints – Contract specifications
### Numerical Example - Corn

<table>
<thead>
<tr>
<th>Bin No.</th>
<th>Quantity</th>
<th>Moisture</th>
<th>TW</th>
<th>DM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9,412</td>
<td>14.5</td>
<td>56.0</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>21,644</td>
<td>14.0</td>
<td>56.0</td>
<td>0.7</td>
<td>2.1</td>
</tr>
<tr>
<td>3</td>
<td>19,302</td>
<td>14.8</td>
<td>55.5</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>31,248</td>
<td>16.7</td>
<td>56.0</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>6,708</td>
<td>12.8</td>
<td>54.0</td>
<td>35.0</td>
<td>6.0</td>
</tr>
<tr>
<td>6</td>
<td>30,927</td>
<td>14.0</td>
<td>56.2</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>7</td>
<td>31,694</td>
<td>16.0</td>
<td>56.8</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>8</td>
<td>2,968</td>
<td>15.0</td>
<td>42.0</td>
<td>5.0</td>
<td>50.0</td>
</tr>
<tr>
<td>9</td>
<td>31,248</td>
<td>14.7</td>
<td>56.0</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>30,979</td>
<td>14.8</td>
<td>56.0</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>11</td>
<td>31,285</td>
<td>13.3</td>
<td>56.8</td>
<td>1.0</td>
<td>3.5</td>
</tr>
<tr>
<td>12</td>
<td>200,759</td>
<td>14.5</td>
<td>55.5</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>13</td>
<td>200,968</td>
<td>14.0</td>
<td>56.0</td>
<td>1.0</td>
<td>2.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Moisture</th>
<th>TW</th>
<th>DM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>451,763</td>
<td>15.0</td>
<td>54.0</td>
<td>5.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discounts, $/bu</th>
<th>Moisture</th>
<th>TW</th>
<th>DM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>
## Results

<table>
<thead>
<tr>
<th>Objective Function</th>
<th>Number of bins</th>
<th>Discount, $</th>
<th>Moisture %</th>
<th>TW, lb/bu</th>
<th>DM, %</th>
<th>FM, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>0</td>
<td>14.14</td>
<td>55.76</td>
<td>1.74</td>
<td>2.58</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>0</td>
<td>14.26</td>
<td>55.70</td>
<td>1.80</td>
<td>2.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bin No.</th>
<th>Bushels</th>
<th>Bin No.</th>
<th>Bushels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9075, 9381</td>
<td>8</td>
<td>2968, 2968</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>10</td>
<td>0, 30979</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>11</td>
<td>31285, 0</td>
</tr>
<tr>
<td>5</td>
<td>6708, 6708</td>
<td>12</td>
<td>200759, 200759</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>13</td>
<td>200968, 200968</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Numerical Example - Soybeans

<table>
<thead>
<tr>
<th>Bin No.</th>
<th>Quantity</th>
<th>Moisture</th>
<th>TW</th>
<th>DM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14,519</td>
<td>11.0</td>
<td>55.7</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>19,903</td>
<td>11.0</td>
<td>55.7</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>20,011</td>
<td>10.8</td>
<td>56.0</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>19,063</td>
<td>11.5</td>
<td>55.0</td>
<td>1.0</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>7,276</td>
<td>12.5</td>
<td>56.0</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>19</td>
<td>29,407</td>
<td>11.0</td>
<td>57.0</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>20</td>
<td>28,900</td>
<td>11.0</td>
<td>57.0</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>21</td>
<td>6,174</td>
<td>11.5</td>
<td>50.3</td>
<td>9.0</td>
<td>28.8</td>
</tr>
<tr>
<td>22</td>
<td>29,154</td>
<td>11.3</td>
<td>57.5</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>23</td>
<td>28,375</td>
<td>11.0</td>
<td>55.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>24</td>
<td>235,275</td>
<td>10.8</td>
<td>55.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>25</td>
<td>50,000</td>
<td>11.0</td>
<td>55.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Moisture</th>
<th>TW</th>
<th>DM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>426,768</td>
<td>14</td>
<td>54</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

| Discounts, $/bu | 0.025 | 0.01 | 0.01 | 0.08 |
## Results

<table>
<thead>
<tr>
<th>Objective Function</th>
<th>No. of bins</th>
<th>Discount, $</th>
<th>Moisture %</th>
<th>TW</th>
<th>DM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>0</td>
<td>10.89</td>
<td>56.06</td>
<td>1.54</td>
<td>1.30</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>0</td>
<td>10.88</td>
<td>55.71</td>
<td>1.50</td>
<td>1.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bin No.</th>
<th>Bushels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0, 13827</td>
</tr>
<tr>
<td>2</td>
<td>0, 19903</td>
</tr>
<tr>
<td>3</td>
<td>0, 20011</td>
</tr>
<tr>
<td>4</td>
<td>16107, 19063</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0, 20103</td>
</tr>
<tr>
<td>7</td>
<td>0, 4906</td>
</tr>
<tr>
<td>8</td>
<td>0, 5962</td>
</tr>
<tr>
<td>9</td>
<td>0, 19174</td>
</tr>
<tr>
<td>10</td>
<td>0, 20011</td>
</tr>
<tr>
<td>11</td>
<td>0, 9517</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>28887, 0</td>
</tr>
<tr>
<td>14</td>
<td>3269</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>29002</td>
</tr>
<tr>
<td>17</td>
<td>0, 27886</td>
</tr>
<tr>
<td>18</td>
<td>0, 1687</td>
</tr>
<tr>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>28900</td>
</tr>
<tr>
<td>21</td>
<td>6174, 6174</td>
</tr>
<tr>
<td>22</td>
<td>29154</td>
</tr>
<tr>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>235275, 235275</td>
</tr>
<tr>
<td>25</td>
<td>50000, 0</td>
</tr>
</tbody>
</table>
Comparison of Blending Results

Blending Results of Elevator Model and New Multi-Objective Optimization Model

Proportion of grain drawn

Storage bin number

Elevator Model
New Model

CORN

SOYBEANS
Sensitivity Analysis

New Contract Specifications – Soybeans Data

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Moisture</th>
<th>TW</th>
<th>DM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>451,763</td>
<td>11.0</td>
<td>56.0</td>
<td>1.0</td>
<td>0.25</td>
</tr>
<tr>
<td>Discounts, $/bu</td>
<td>0.025</td>
<td>0.01</td>
<td>0.01</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Results

<table>
<thead>
<tr>
<th>Objective Function</th>
<th>Number of bins</th>
<th>Discount, $</th>
<th>Moisture, %</th>
<th>TW, lb/bu</th>
<th>DM, %</th>
<th>FM, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9</td>
<td>23,140</td>
<td>10.89</td>
<td>56.06</td>
<td>1.54</td>
<td>1.30</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>17,057</td>
<td>10.92</td>
<td>56.07</td>
<td>1.00</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Pareto Optimal Solutions

<table>
<thead>
<tr>
<th>Pareto Optimal Solution</th>
<th>No. of bins</th>
<th>Discount $</th>
<th>Moisture</th>
<th>TW</th>
<th>DM</th>
<th>FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>18490</td>
<td>10.83</td>
<td>56.14</td>
<td>1.00</td>
<td>0.79</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>17071</td>
<td>10.87</td>
<td>56.07</td>
<td>1.00</td>
<td>0.75</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>17061</td>
<td>10.90</td>
<td>56.07</td>
<td>1.00</td>
<td>0.75</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>17412</td>
<td>10.87</td>
<td>56.07</td>
<td>1.00</td>
<td>0.76</td>
</tr>
</tbody>
</table>

![Graph showing Pareto Optimal Solutions](image_url)
Conclusions

- The proposed mixed integer multi-objective model provides better blending results than the elevator optimization model.
- Minimization of risk in terms of level of aggregation.
- High fraction of grain quantity from each bin is used – chance for cleanouts.
- Logistically easier to use fewer bins.
- Time saving in loading the train.
- Pareto optimal solutions – Management decision.
Directions for Future Research

- Optimization model for storage bin assignment for incoming lots
- Combination of both models for minimization of food security risk
- Include logistics data to improve the model
- Include discount given to farmer to compute overall profit
Maitri Thakur
Department of Agricultural and Biosystems Engineering
Department of Industrial and Manufacturing Systems Engineering
Iowa State University, Ames, IA
maitri@iastate.edu