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

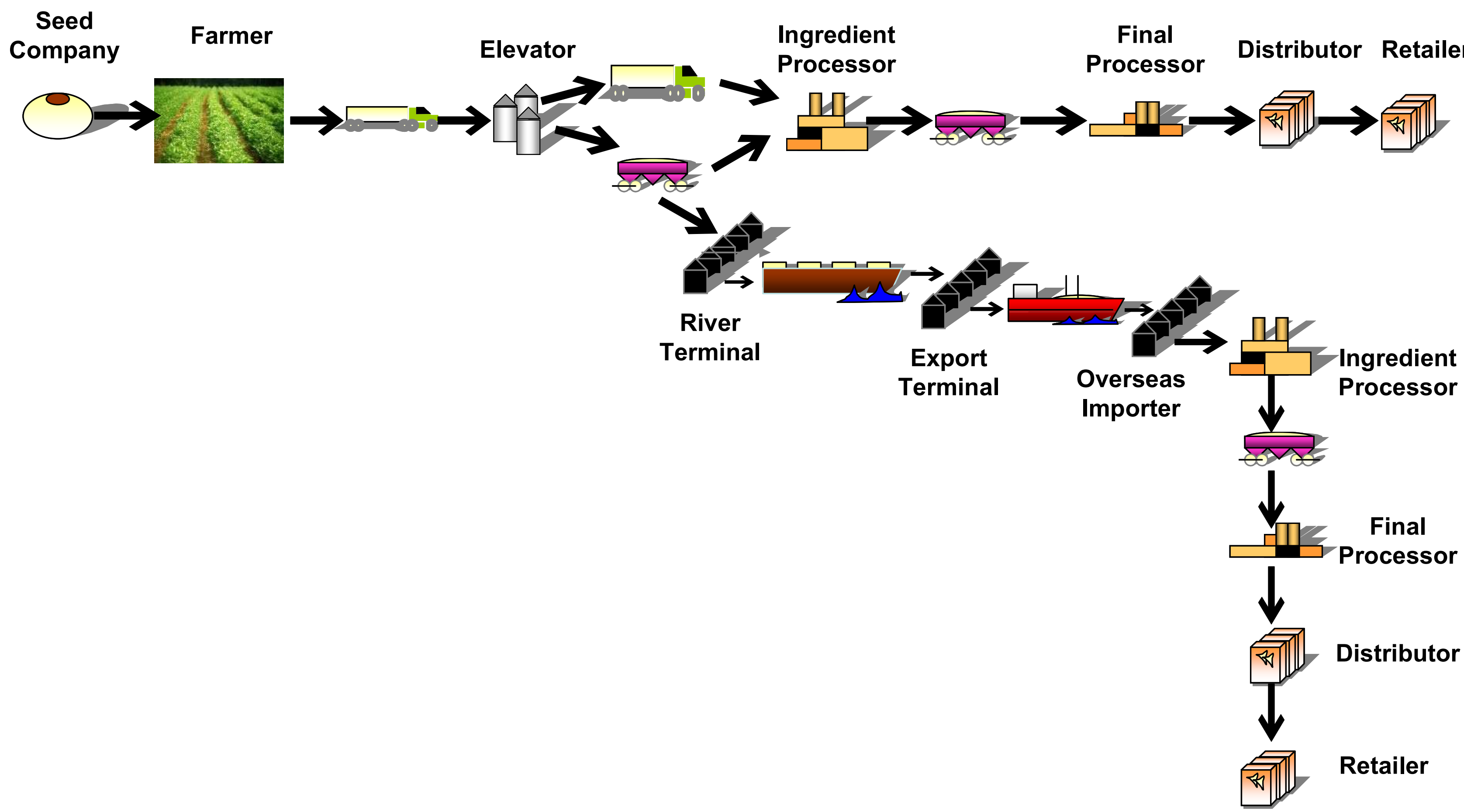
- Several Food Safety and Traceability Regulations exist in different countries
  - EU’s General Food Law
  - Bioterrorism Act of 2002
  - CanTrace
- Bioterrorism Act of 2002
  - Self registration
  - Maintain records to identify immediate previous sources and subsequent recipients of food
- Timeliness
  - In case of an outbreak, FDA requires that a company produce requested records within a 24 hour time period.

Traceability terminology

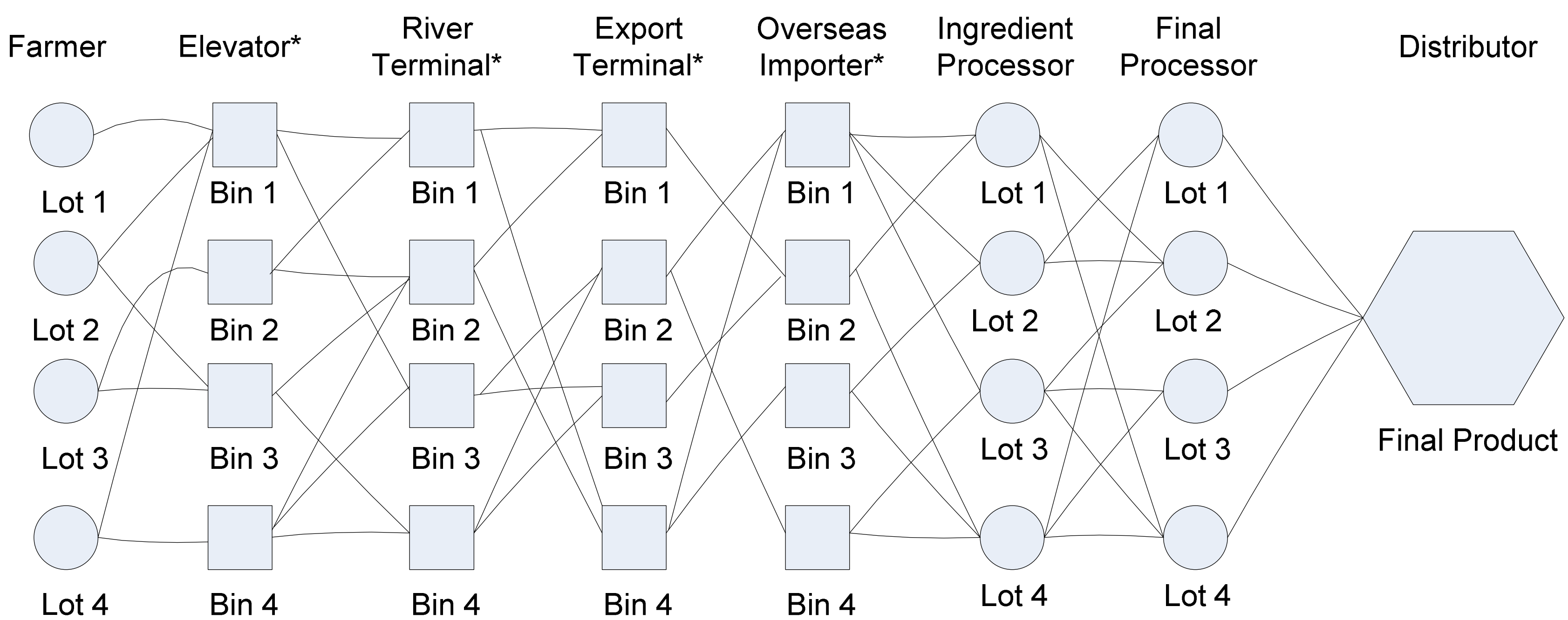
- Internal Traceability and Chain Traceability
  - Internal traceability – keeping track of all physical entities and their transformations that take place within an enterprise
  - Chain traceability – Information sharing between different enterprises in a supply chain

- 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

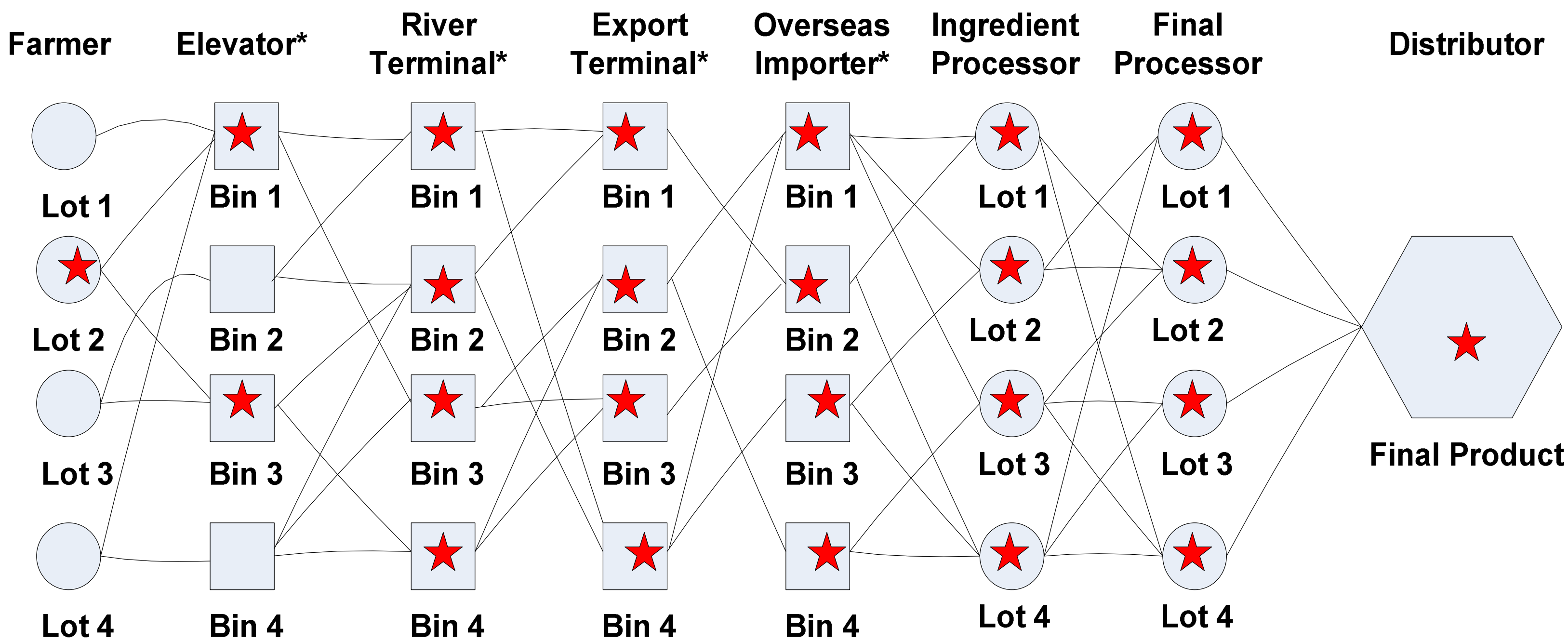


Typical Grain Lot Blending Scenario



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

Contaminated Lot Consequences

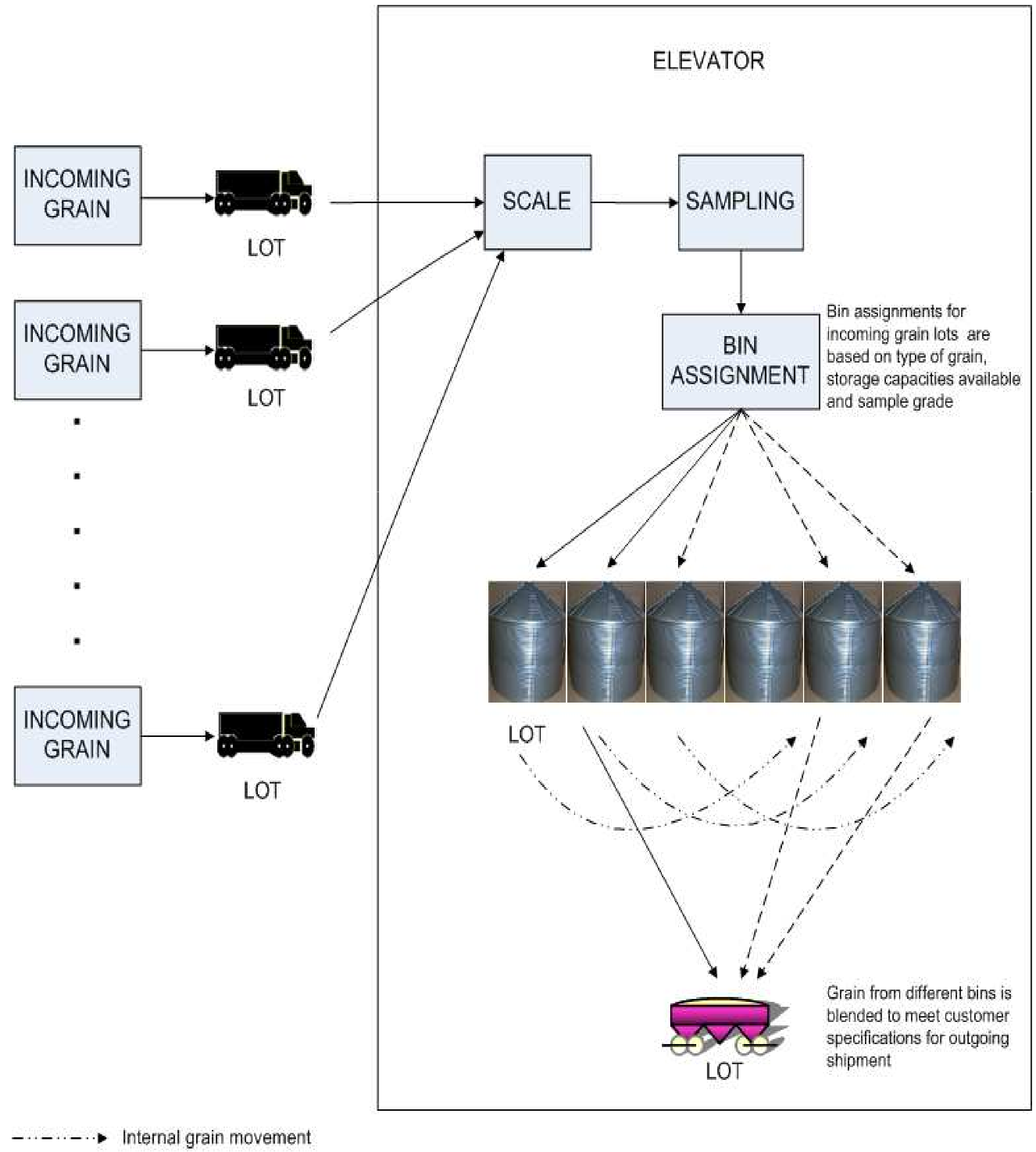


*Bin- Storage bin, each bin is considered as one lot

★ - 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

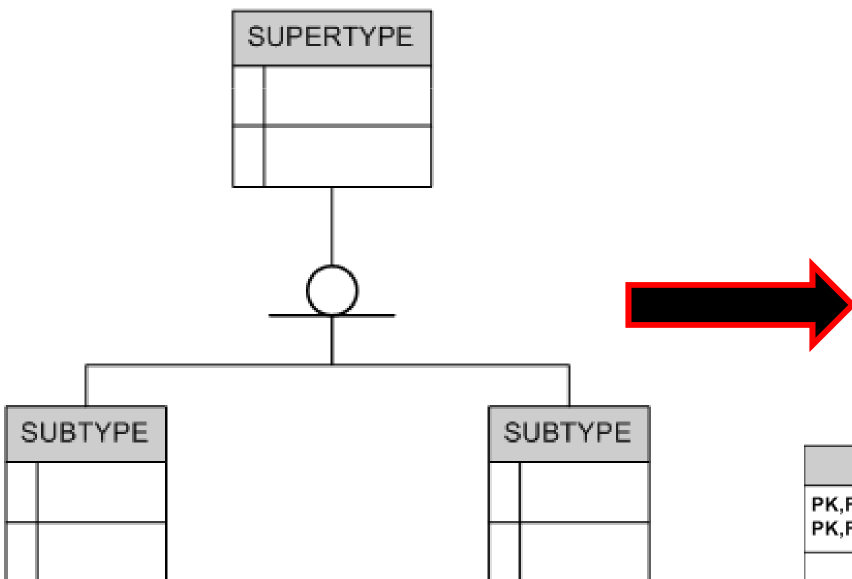
- Timeliness is key in food safety and traceability
- Need to establish relations between physical entities, their transformations and records of their suppliers and customers
- Relational data modeling techniques are used extensively for operational management programs
- Not common in agricultural industry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

Methodology

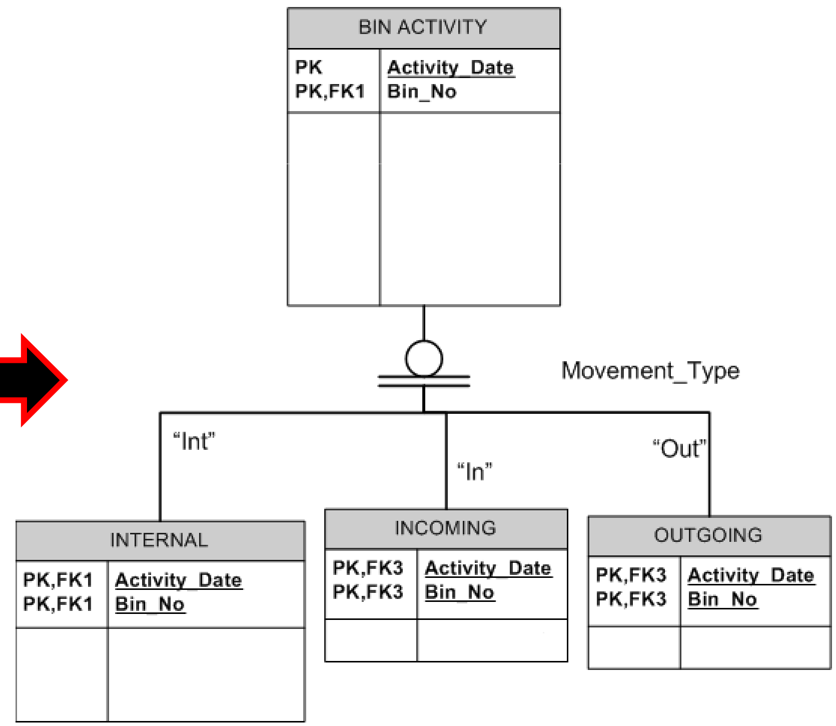
- Entity-Relationship Model (E/RM) for modeling operational data
- E/RM differentiates between entities, relationships and attributes
- mE/RM is a specialization of E/RM and is suitable for conceptual modeling of OLAP (Online Analytical Processing) applications
- E/RM tested using the operational data 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.

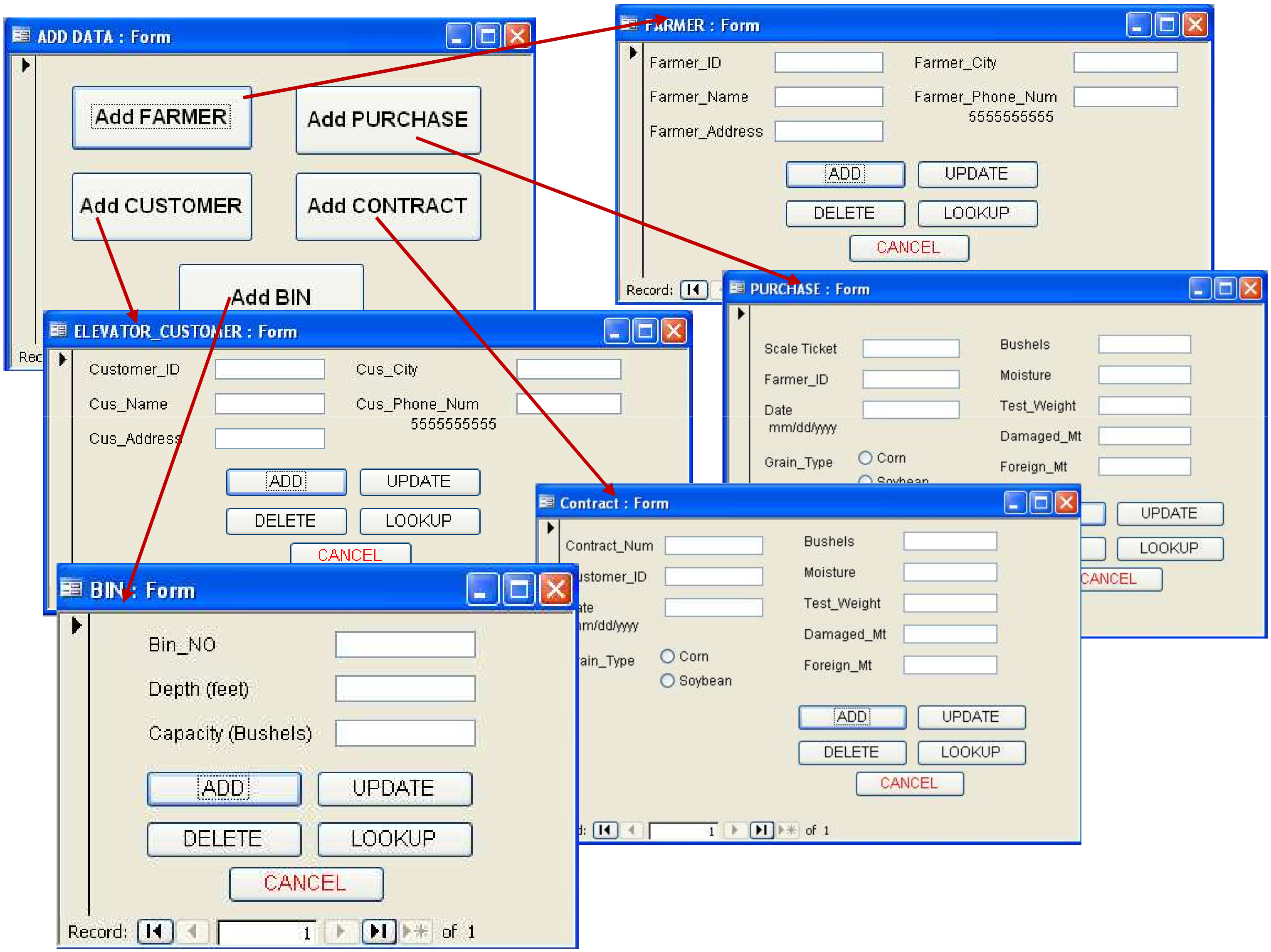


General Form



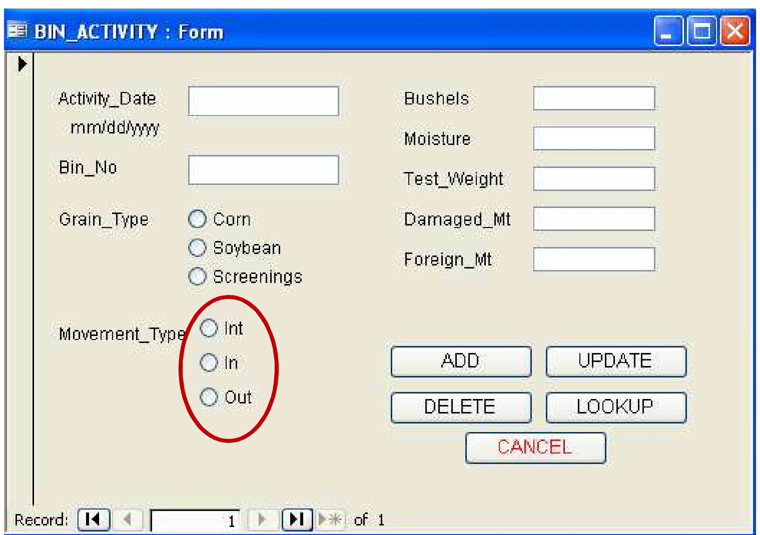
Grain bin activity sub-types

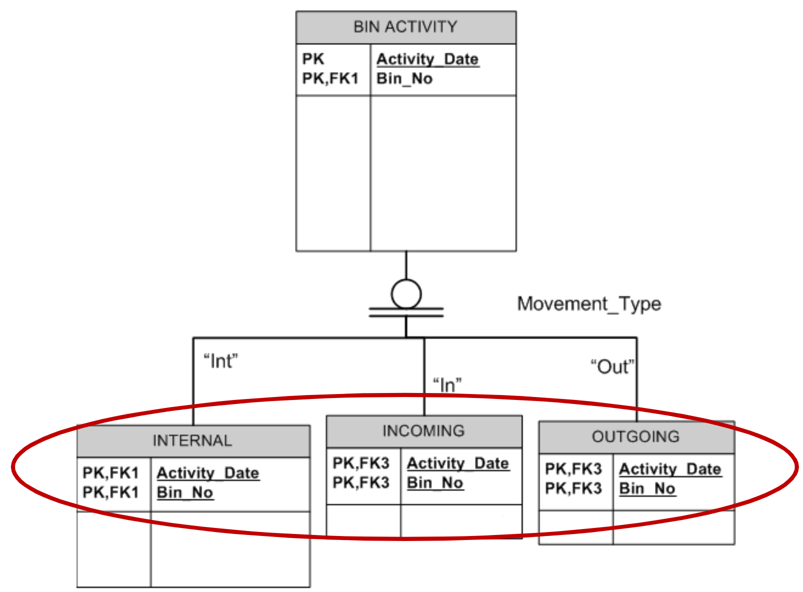
User Interface



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 : $\frac{\text{Track-able Quantity}}{\text{Contaminated Quantity}}$
  - 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

ACTIVITY_DATE	CONTRACT_NUM	CUSTOMER_ID	BIN_NO	RAIL_ID	RAILCAR_ID	BUSHELS
25-MAR-08 10.25.00.000000 AM	C032208	C0001	2	10001	01	-5000
25-MAR-08 10.25.00.000000 AM	C032208	C0001	8	10001	01	-2000
28-APR-08 11.30.00.000000 AM	A042508	C0002	11	10001	11	-6000
28-MAR-08 10.25.00.000000 AM	CG040608	C0005	2	10003	12	-664
25-MAR-08 10.25.00.000000 AM	C032208	C0001	2	10001	01	-2000
25-MAR-08 10.25.00.000000 AM	C032208	C0001	8	10001	01	-5000
29-APR-08 09.25.00.000000 AM	G042808	C0003	9	10002	02	-5000

Results
Tracking and Tracing

Sample Outputs

ACTIVITY_DATE	CONTRACT_NUM	CUSTOMER_ID	BIN_NO	RAIL_ID	RAILCAR_ID	BUSHELS
25-MAR-08 10.25.00.000000 AM	C032208	C0001	2	10001	01	-5000
25-MAR-08 10.25.00.000000 AM	C032208	C0001	8	10001	01	-2000
28-APR-08 11.30.00.000000 AM	A042508	C0002	11	10001	11	-6000
28-MAR-08 10.25.00.000000 AM	CG040608	C0005	2	10003	12	-664
25-MAR-08 10.25.00.000000 AM	C032208	C0001	2	10001	01	-2000
25-MAR-08 10.25.00.000000 AM	C032208	C0001	8	10001	01	-5000
29-APR-08 09.25.00.000000 AM	G042808	C0003	9	10002	02	-5000

SCALE_TICKET	PURCHASE_DATE	FARMER_NAME	BIN_NO	BUSHELS	ACTIVITY_DATE	CONTRACT_NUM	CUS_NAME	BIN_NO	SHIP_MODE	BUSHELS
1011	15-MAR-08	Ron Penning	2	1564	28-MAR-08 10.25.00.000000 AM	CG040608	21st Century Grain Processing	2	R	-664
1010	15-MAR-08	Ron Penning	2	2200	28-MAR-08 10.25.00.000000 AM	CG040608	21st Century Grain Processing	2	R	-664
1019	16-MAR-08	John Smith	9	1508	02-MAY-08 02.25.00.000000 PM	CG040608	21st Century Grain Processing	9	T	-4000
1020	16-MAR-08	John Smith	9	2124	02-MAY-08 02.25.00.000000 PM	CG040608	21st Century Grain Processing	9	T	-4000
1018	16-MAR-08	John Smith	9	3200	02-MAY-08 02.25.00.000000 PM	CG040608	21st Century Grain Processing	9	T	-4000
1046	16-MAR-08	Pat Torreson	9	3025	02-MAY-08 02.25.00.000000 PM	CG040608	21st Century Grain Processing	9	T	-4000
1047	16-MAR-08	Pat Torreson	9	4205	02-MAY-08 02.25.00.000000 PM	CG040608	21st Century Grain Processing	9	T	-4000
1045	16-MAR-08	Pat Torreson	9	4850	02-MAY-08 02.25.00.000000 PM	CG040608	21st Century Grain Processing	9	T	-4000

Results
Performance Indicators

	Number of recalls	Mean Response Time (minutes)	Tracking Efficiency
Without ER/M	41	804.0* (13.4 hours)	Uncertain
With ER/M	20	<1.0	100%

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

* Reference: Chad M. Laux (2007). The impacts of a formal quality management system: a case study of implementing ISO 9000 at Farmers Cooperative Co., Iowa

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

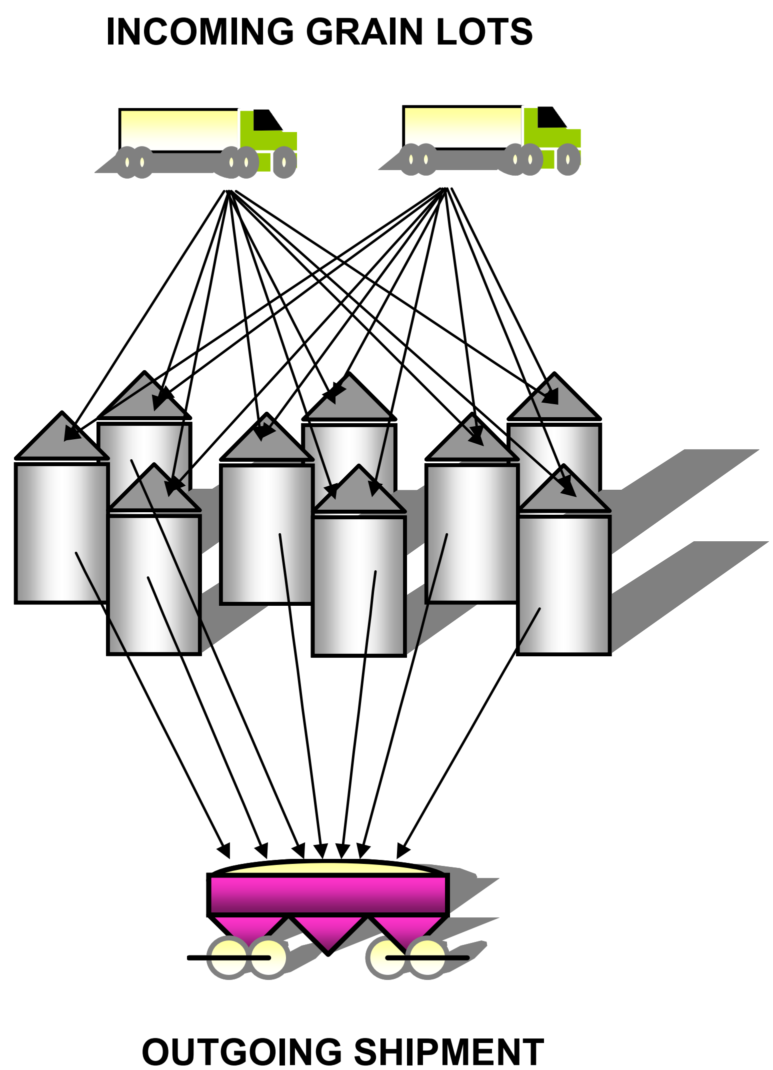
- Cost of implementation and maintenance to be considered

- 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

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

	Quantity	Moisture	TW	DM	FM
	451,763	**15.0**	**54.0**	**5.0**	**3.0**
Discounts, $/bu		**0.02**	**0.02**	**0.03**	**0.01**

Results

Objective Function	Number of bins	Discount, $	Moisture %	TW, lb/bu	DM, %	FM, %
1	6	0	14.14	55.76	1.74	2.58
2	6	0	14.26	55.70	1.80	2.46

Bin No.	Bushels	Bin No.	Bushels
1	9075, 9381	8	2968, 2968
2	0	9	0
3	0	10	0, 30979
4	0	11	31285, 0
5	6708, 6708	12	200759, 200759
6	0	13	200968, 200968
7	0		

Numerical Example - Soybeans

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

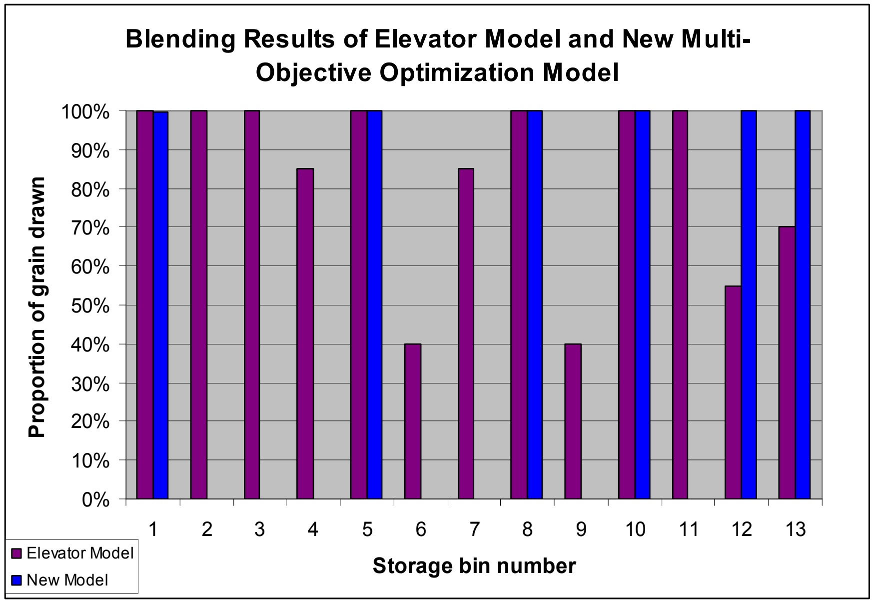
	Moisture	TW	DM	FM
Quantity				
426,768	**14**	**54**	**3**	**2**
Discounts, $/bu	**0.025**	**0.01**	**0.01**	**0.08**

Results

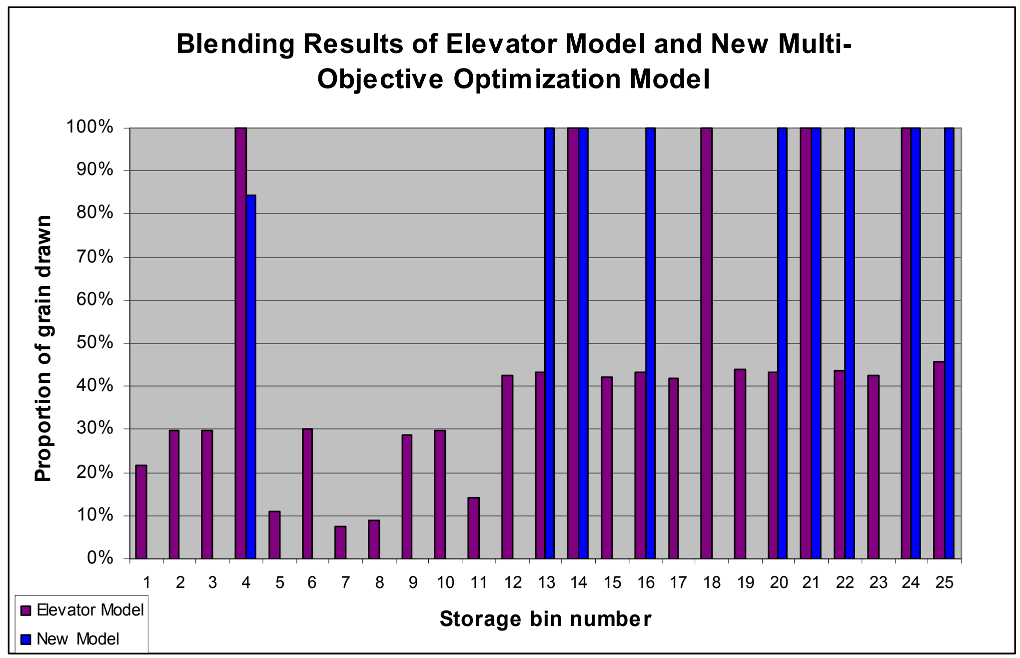
Objective Function	No. of bins	Discount, $	Moisture %	TW	DM	FM
1	9	0	10.89	56.06	1.54	1.30
2	15	0	10.88	55.71	1.50	1.32

Bin No.	Bushels	Bin No.	Bushels
1	0, 13827	14	3269, 3269
2	0, 19903	15	0
3	0, 20011	16	29002, 0
4	16107, 19063	17	0, 27886
5	0	18	0, 1687
6	0, 20103	19	0
7	0, 4906	20	28900, 0
8	0, 5962	21	6174, 6174
9	0, 19174	22	29154, 0
10	0, 20011	23	0
11	0, 9517	24	235275, 235275
12	0	25	50000, 0
13	28887, 0		

Comparison of Blending Results



CORN



SOYBEANS

Sensitivity Analysis

New Contract Specifications – Soybeans Data

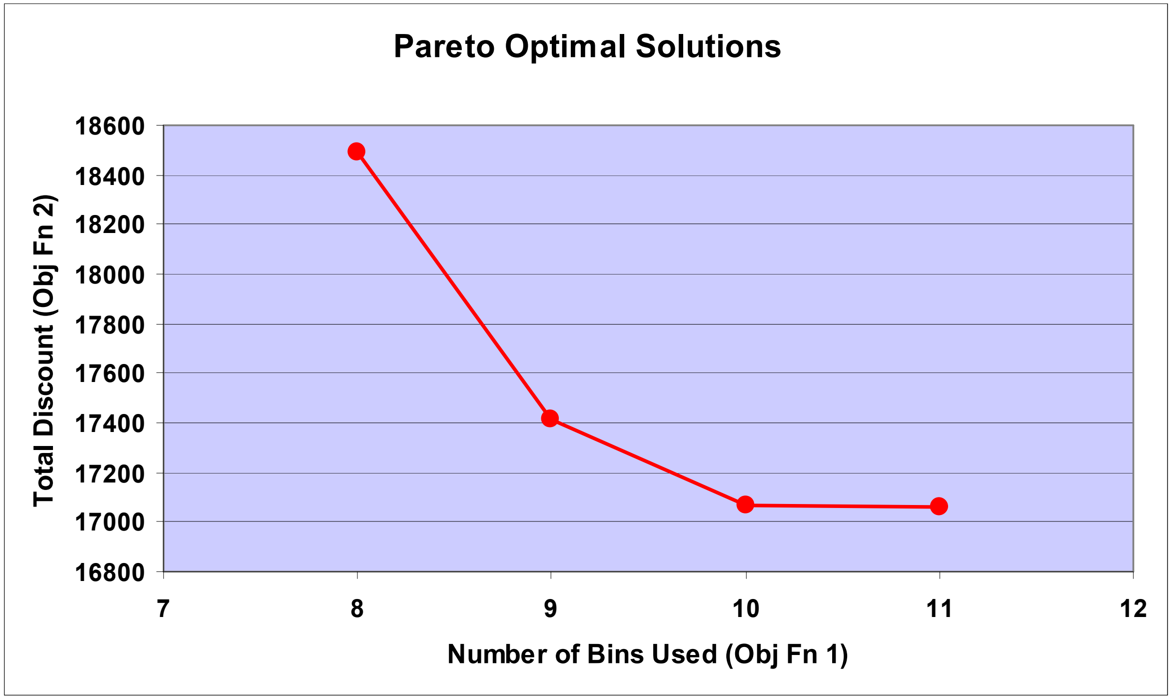
Quantity	Moisture	TW	DM	FM
451,763	11.0	56.0	1.0	0.25
Discounts, $/bu	0.025	0.01	0.01	0.08

Results

Objective Function	Number of bins	Discount, $	Moisture, %	TW, lb/bu	DM, %	FM, %
1	9	23,140	10.89	56.06	1.54	1.30
2	14	17,057	10.92	56.07	1.00	0.75

Pareto Optimal Solutions

Pareto Optimal Solution	No. of bins	Discount $	Moisture	TW	DM	FM
1	8	18490	10.83	56.14	1.00	0.79
2	10	17071	10.87	56.07	1.00	0.75
3	11	17061	10.90	56.07	1.00	0.75
4	9	17412	10.87	56.07	1.00	0.76



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

THANK YOU

http://www.extension.iastate.edu/grain/

Maitri Thakur
Department of Agricultural and Biosystems Engineering
Department of Industrial and Manufacturing Systems Engineering
Iowa State University, Ames, IA
maitri@iastate.edu

www.grainlab.org
Grain Quality LABORATORY
IOWA STATE UNIVERSITY