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Shelling Update

USDA

FORT VALLEY STATE UNIVERSITY

I LOVE pecans

NPSA NATIONAL PECAN SHELLERS ASSOCIATION

Motivation

- Shelling processes have not seen significant innovation compared to other post-harvest areas.

- Efficient optimization of shelling process will significantly impact pecan post-harvesting results.

- Implement advanced technologies to provide smarter machines and fine-tune shelling processes to control pecan half-yields and to promote overall effectiveness.

Research Objectives

1. Determine relationship between sheller processing parameters and pecan half-yield.
2. Evaluate impact of moisture on half-yield during shelling process.
3. Examine effects of different paddle shaft configurations on pecan half-yield

Equipment

Modifications

Mod 1 – Replacement of metal panels with clear panels.

Mod 2 – Implementation of partitioned output locations.

Mod 3 – Instrumentation of digital displays for shaft and drum rpm.

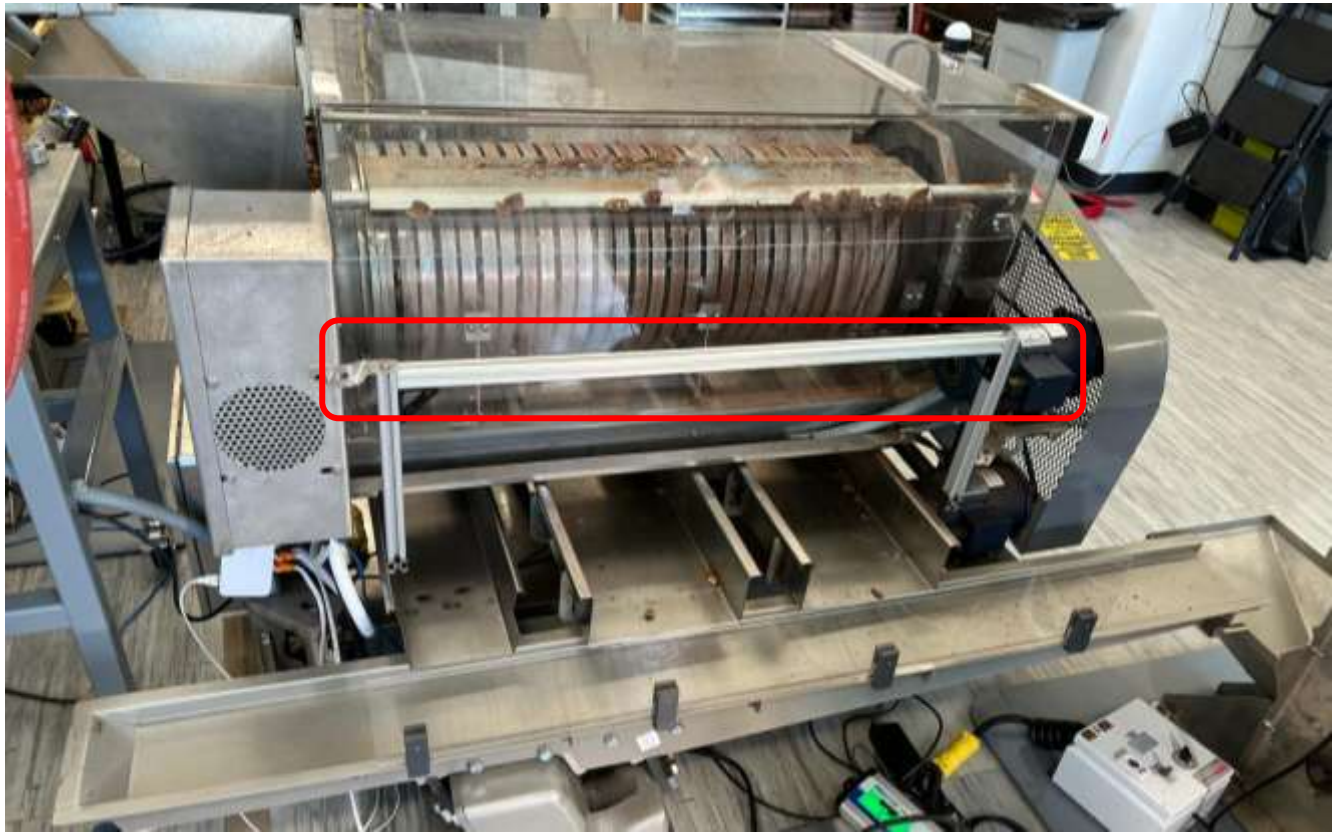
Mod 4 – Instrumentation of Machine feet for tilt angle automation.

Mod 5 – Digital control for mods 3 and 4

Modifications (Cont.)

Mod 6- Automatic transition to the sheller and blower

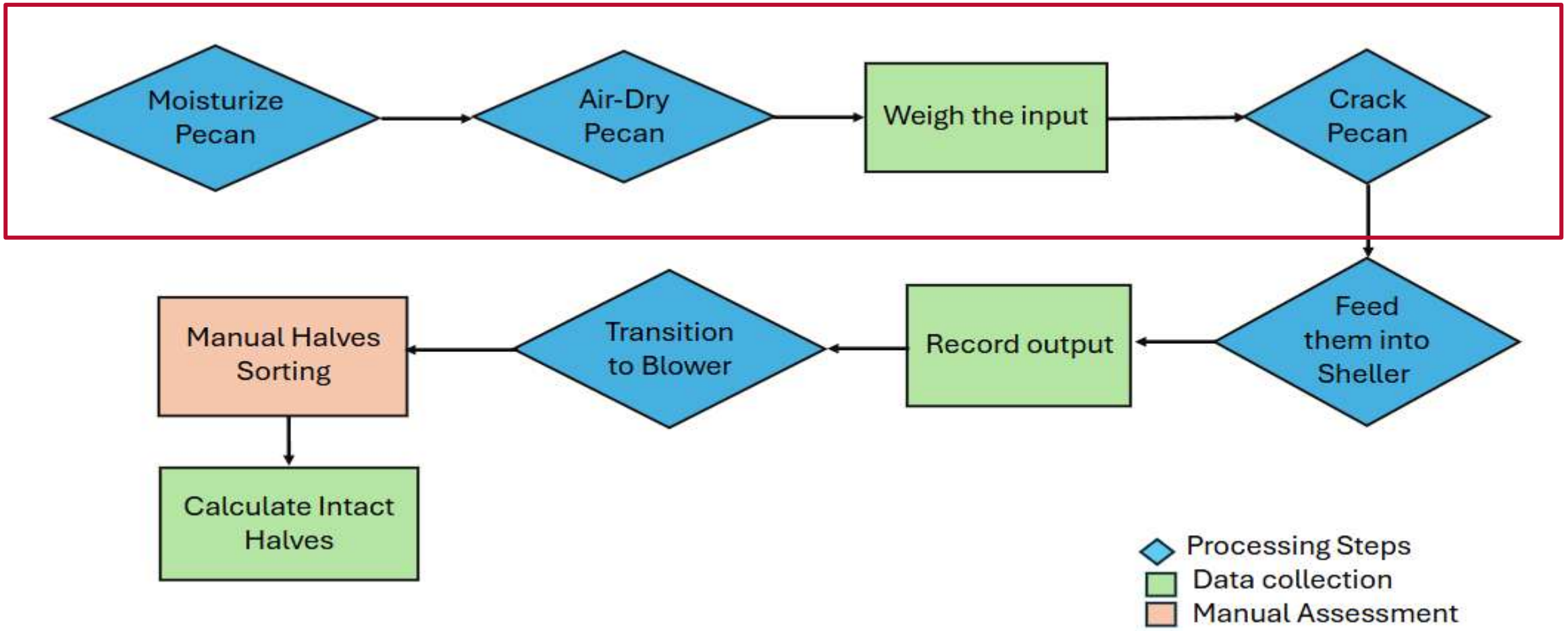
Mod 7 – Implementation of cameras on output



Design of Experiments

Research Objectives (RO)	Independent Variables	Variations / Levels					Unit
RO1	Ring Gap	+0.0	+1/16	+1/8			In.
	Paddle Shaft Velocity	400	600	800			RPM
	Machine Tilt Angle	2.5	3.5	5			θ
	Drum Velocity	25	30	35			RPM
RO2	Moisture Level	5-9					%
RO3	Pin Material	Steel	Half Steel	Alumi num	Nylon	Polyet hylene	
	Pin Length	Standard	Short	Medium			
	Ring Gap	+0.0	+1/16	+1/8			In.
	Paddle Shaft Velocity	375-1100					RPM

Experimental Procedure for RO1



Terminology

- Weight Distribution: % of the sheller output that exited from a specific segment of the sheller

$$Weight\ \ Distribution\ (\%) = \frac{Segmented\ \ Output}{Sheller\ \ Output}$$

- Discharge: Material that exits the end of the sheller without being properly shelled

$$Discharge\ \ Throughput = \left(\frac{Total\ \ Discharge}{Sheller\ \ Input}\right) \times 100$$

- Loss: Percentage difference between weight of the final output and weight of the input

$$Loss = \left(1 - \frac{Sheller\ \ Output + Final\ \ Discharge}{Sheller\ \ Input}\right) \times 100$$

Data Structure

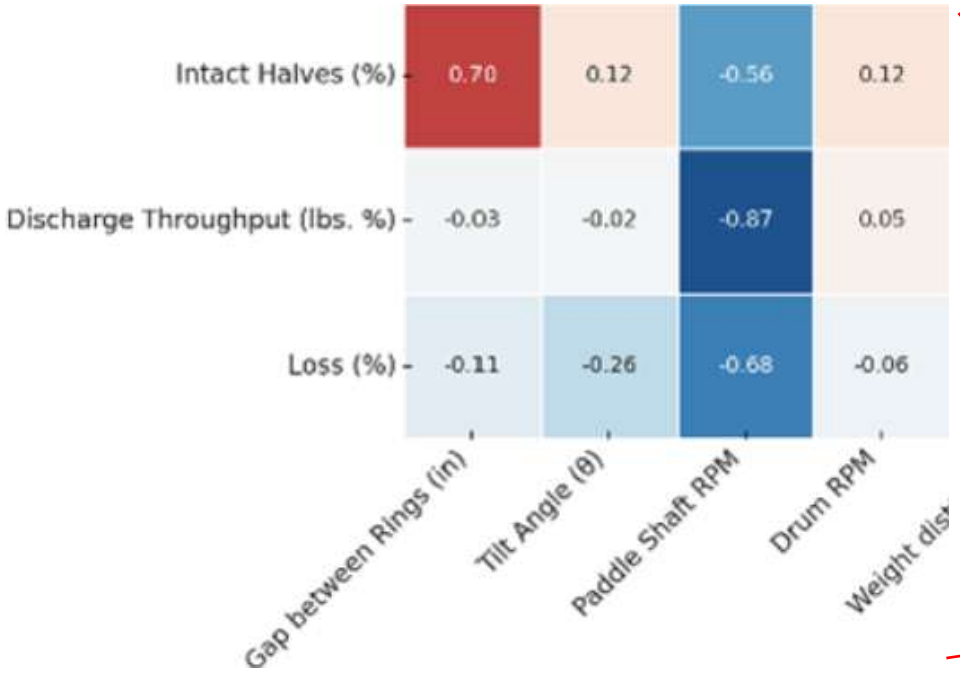
= Independent variable

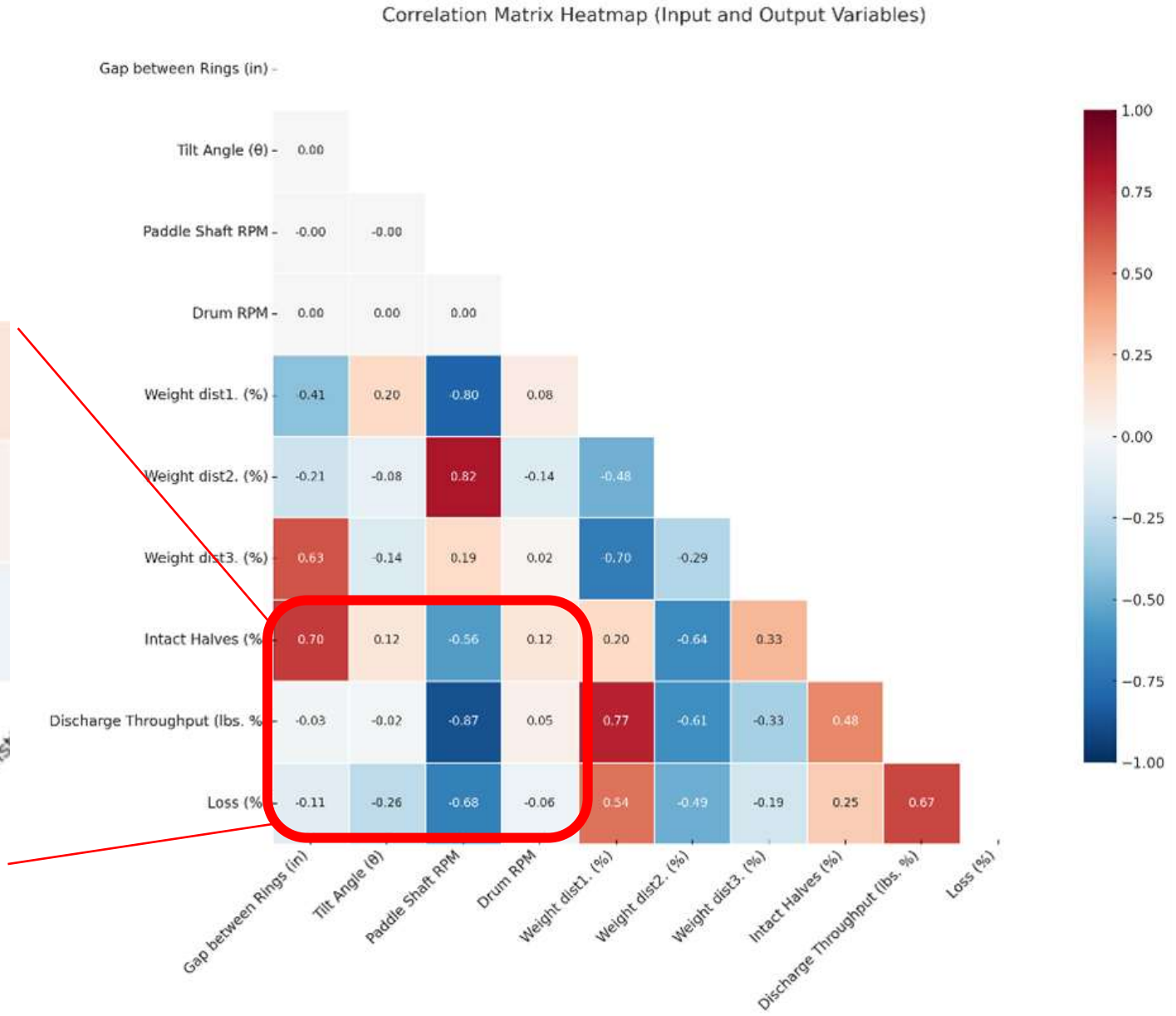
= Dependent variable

Ring Gap (in)	Paddle Shaft RPM	Drum RPM	Moisture Level (%)	Intact Halves (%)	Weight dist1. (%)	Weight dist2. (%)	Weight dist3. (%)	Discharge Throughput (lbs. %)	Loss (%)
0.39	400	30	7.52	64.76	27.6	24.8	47.6	156.05	11.4
0.39	600	30	7.52	43.68	22.2	24.8	53	32.4	7.02
0.39	800	30	7.06	29.99	18.9	30.3	50.8	12.9	2.7
0.45	400	30	7.2	77	24.6	21.8	53.6	110.4	7.9
0.45	600	30	6.7	65.62	16.75	24.55	58.7	16.04	8.44
0.45	800	30	6.7	58.7	16.83	34.41	48.76	0	5.78
0.49	400	30	6.86	87.79	18.6	21.5	59.9	170.5	4.08
0.49	600	30	7.16	79.05	13.5	21.3	65.2	25.7	8.76
0.49	800	30	7.4	72.61	11.8	27.3	60.9	10.3	6.49

*All experiments were conducted using Desirables pecan variety and a 14” sheller in a controlled environment

Correlation Matrix





Analysis of Variance (ANOVA) on Half Yield

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Paddle Shaft RPM	2	2367	1183.58	11.98	0.000
Error	51	5037	98.76		
Total	53	7404			

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Gap between Rings (in)	2	3705	1852.61	25.55	0.000
Error	51	3699	72.52		
Total	53	7404			

Analysis of Variance

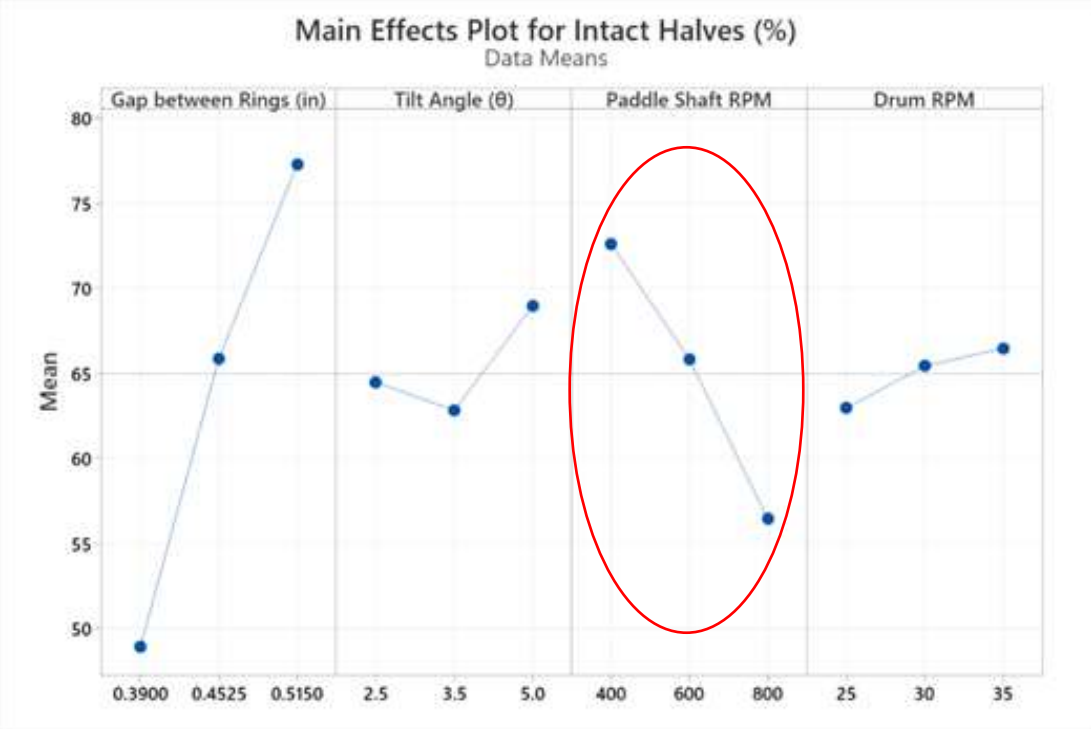
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Drum RPM	2	117.3	58.63	0.41	0.666
Error	51	7286.5	142.87		
Total	53	7403.8			

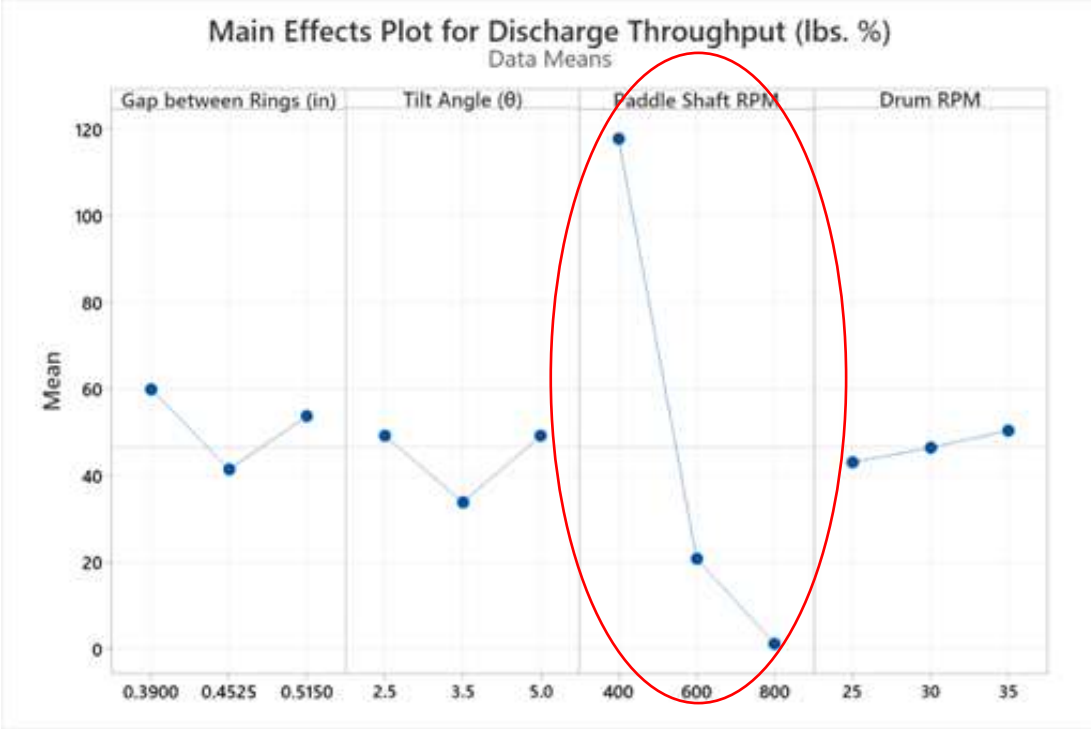
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Tilt Angle (θ)	2	193.3	96.66	0.68	0.509
Error	51	7210.4	141.38		
Total	53	7403.8			

**Statistical significance threshold: p-value < 0.05*

Main Effects





Half-Yield Optimization

Variable Ranges

Variable	Values
Gap between Rings (in)	(0.39, 0.49)
Tilt Angle (θ)	(2.5, 5)
Paddle Shaft RPM	(400, 800)
Drum RPM	(25, 35)
Moisture Level (%)	(4.5, 9)

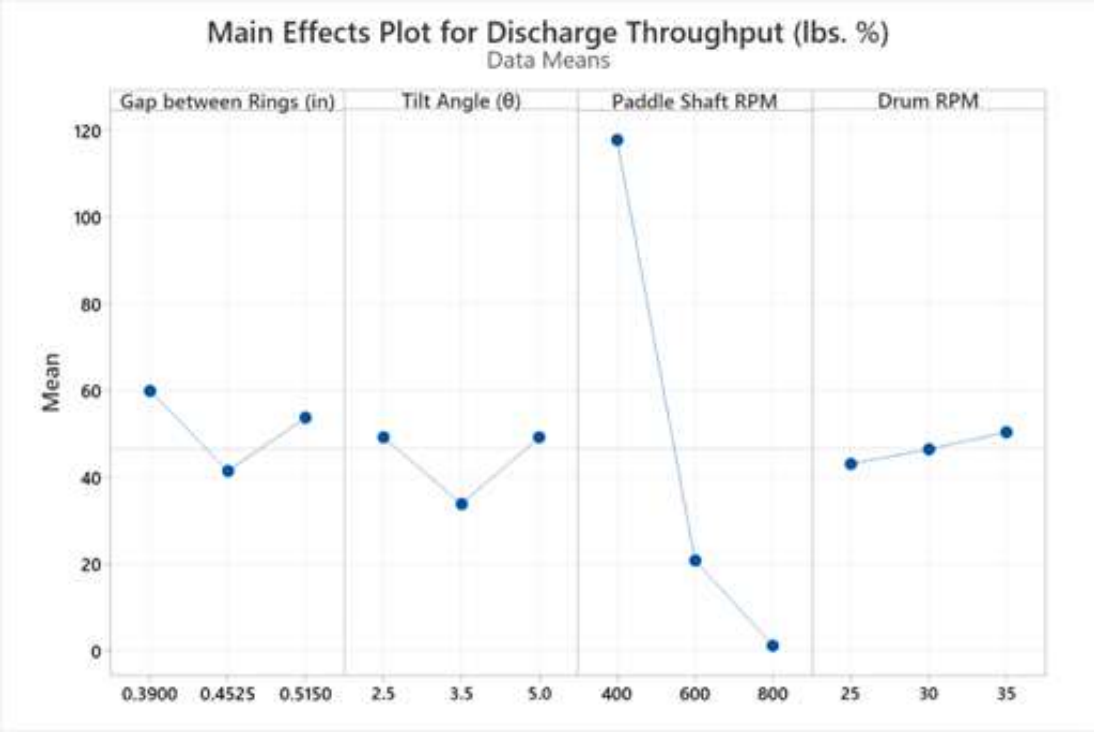
Solution

Solution	Gap between Rings (in)	Tilt Paddle Angle (θ)	Shaft RPM	Drum RPM	Moisture Level (%)
1	0.455657	2.5	400	31.5657	9

Discharge/Yield Optimization

Variable Ranges

Variable	Values
Gap between Rings (in)	(0.39, 0.49)
Tilt Angle (θ)	(2.5, 5)
Paddle Shaft RPM	(400, 800)
Drum RPM	(25, 35)
Moisture Level (%)	(4.5, 9)



Discharge/Yield Optimization

Sensitivity Analysis		Intact Halves (%)	Discharge Throughput (lbs. %)	Intact Halves (%)	Discharge Throughput (lbs. %)	Intact Halves (%)	Discharge Throughput (lbs. %)	Intact Halves (%)	Discharge Throughput (lbs. %)	Intact Halves (%)	Discharge Throughput (lbs. %)
		Importance Weight		Importance Weight		Importance Weight		Importance Weight		Importance Weight	
		9	1	8	2	7	3	6	4	5	5
		Obtained Values		Obtained Values		Obtained Values		Obtained Values		Obtained Values	
Machine Settings	Gap between Rings (in)	0.456		0.461		0.463		0.465		0.466	
	Tilt Angle (θ)	2.5		2.5		2.5		2.5		2.5	
	Paddle Shaft RPM	400		484.848		549.54		597.980		634.34	
	Drum RPM	31.16		31.061		30.96		30.65		30.35	
	Moisture Level (%)	9		9		9		9		9	

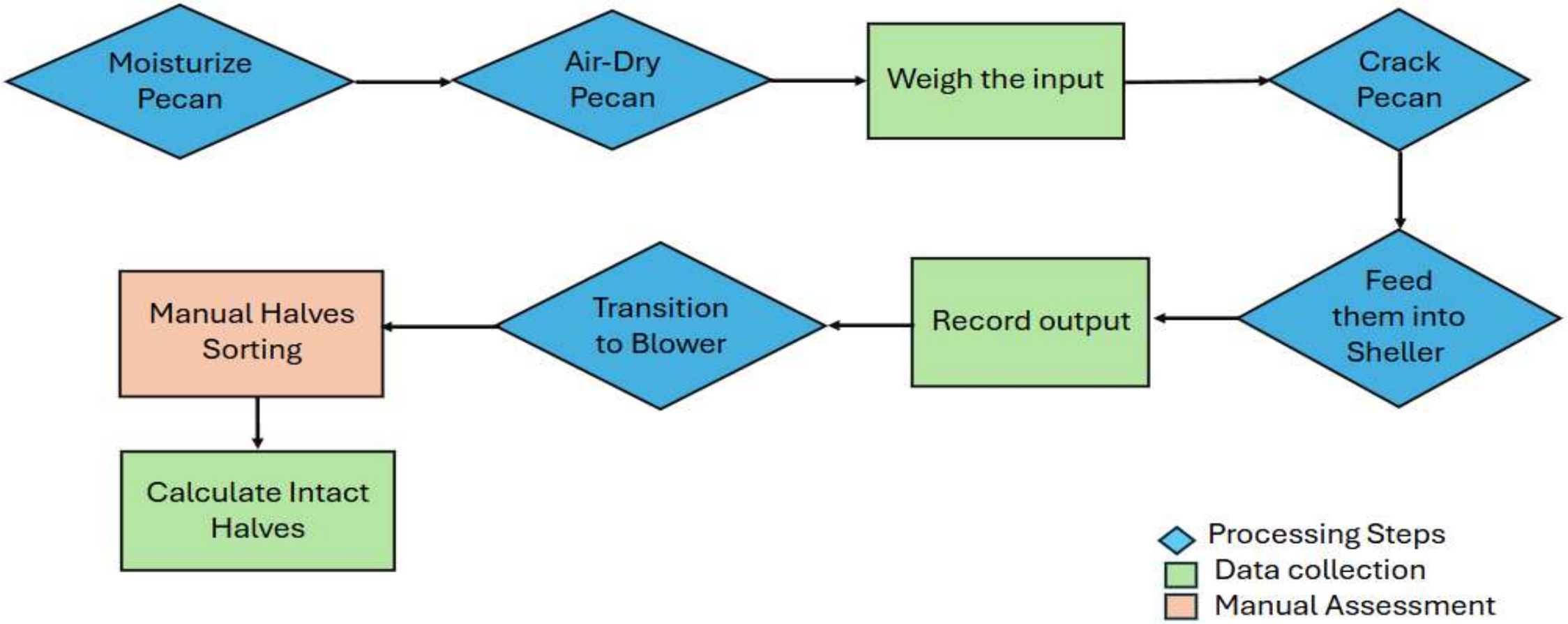
R01 Recommendations

- Paddle Shaft RPM and Ring Gap have the only significant sheller effect on Half-Yield
  - ↑ Paddle Shaft RPM = ↓ Half-Yield
  - ↑ Ring Gap = ↑ Half-Yield
- Optimal Half-Yield and Discharge settings conflict with each other
  - Settings combinations will depend on facility configuration

Design of Experiments

Research Objectives (RO)	Independent Variables	Variations / Levels					Unit
RO1	Ring Gap	+0.0	+1/16	+1/8			In.
	Paddle Shaft Velocity	400	600	800			RPM
	Machine Tilt Angle	2.5	3.5	5			θ
	Drum Velocity	25	30	35			RPM
RO2	Moisture Level	5-9					%
RO3	Pin Material	Steel	Half Steel	Alumi num	Nylon	Polyet hylene	
	Pin Length	Standard	Short	Medium			
	Ring Gap	+0.0	+1/16	+1/8			In.
	Paddle Shaft Velocity	375-1100					RPM

Experimental Procedure for RO2



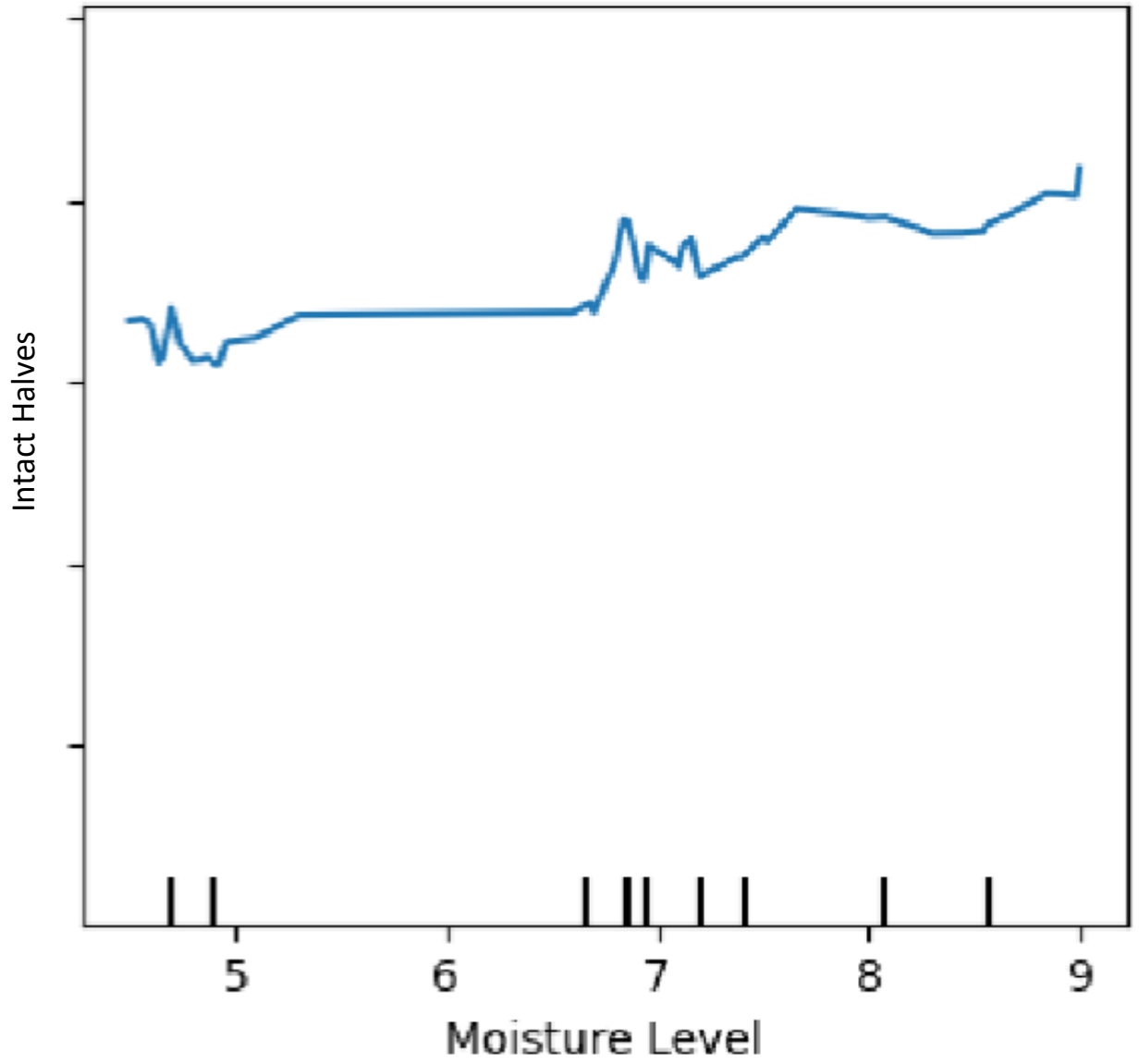
Moisture Results

Table: ANOVA Test (p-values)

Variable	Intact Halves	Discharge Throughput	Loss
Moisture	**0.00012**	0.09172	0.11498
Ring Gap	**4.10e-09**	**0.00654**	0.12429
Paddle Shaft RPM	**1.5e-09**	**1.56e-21**	**1.05e-08**
Drum RPM	0.93031	0.58696	0.06745

Results Cont.

- Generally, increased moisture has a positive effect on half-yield



Moisture Optimization

Machine Settings	Moisture Level (%)	9	9	7.5	7	6.18	4.54
	Tilt Angle (θ)	2.5	2.5	2.5	2.5	4.57	2.5
	Paddle Shaft RPM	400	400	400	400	400	400
	Drum RPM	31.57	35	31.57	31.57	35	25
	Ring Gap	0.456	0.488	0.456	0.456	0.47	0.39

RO2 Recommendations

- Moisture has a significant effect on sheller performance, and overall half-yield
- An increase in moisture will generally increase half-yield
- Optimizations can be made at lower levels, but the maximum yield will decrease

Design of Experiments

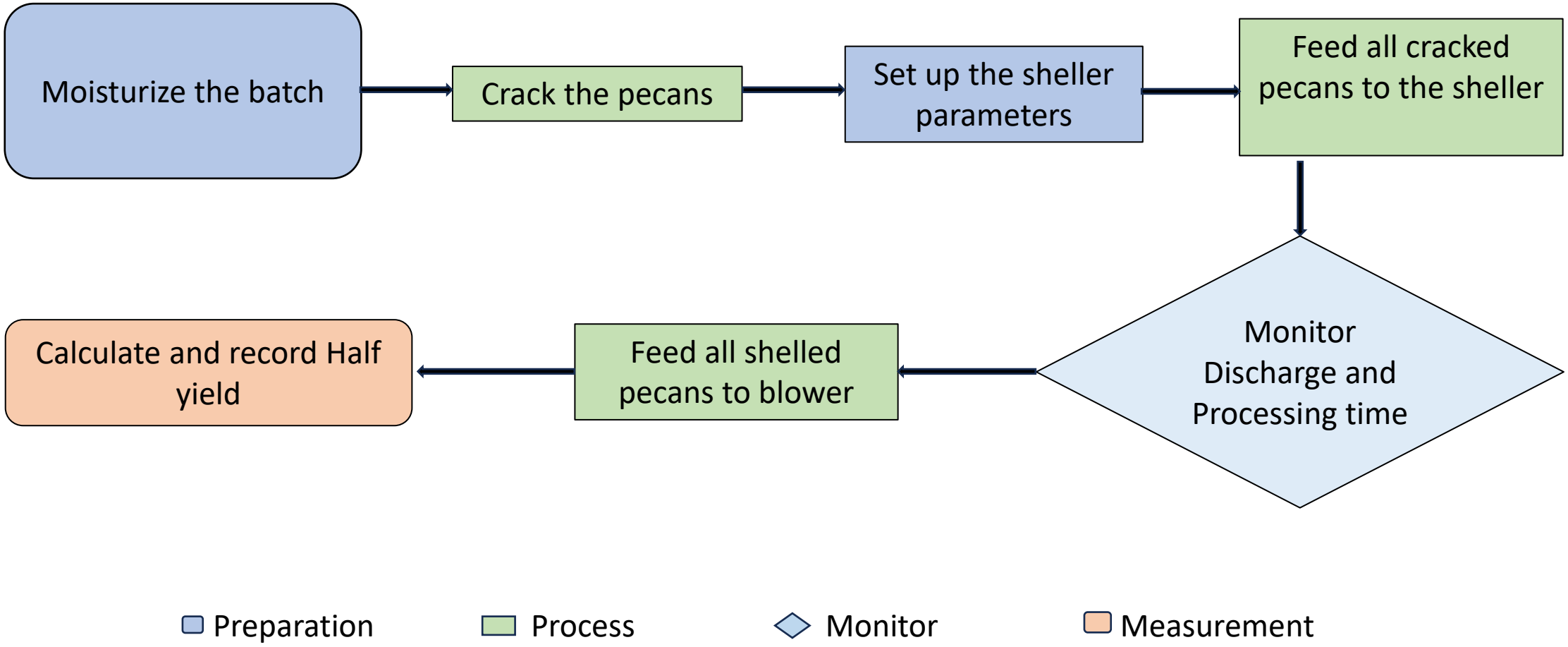
Research Objectives (RO)	Independent Variables	Variations / Levels					Unit
RO1	Ring Gap	+0.0	+1/16	+1/8			In.
	Paddle Shaft Velocity	400	600	800			RPM
	Machine Tilt Angle	2.5	3.5	5			θ
	Drum Velocity	25	30	35			RPM
RO2	Moisture Level	5-9					%
RO3	Pin Material	Steel	Half length Steel	Alumi num	Nylon	Polyethyle ne	
	Pin Length	Standard	Short	Medium			
	Ring Gap	+0.0	+1/16	+1/8			In.
	Paddle Shaft Velocity	375-1100					RPM

Equipment

Figure: 18-inch Sheller

Figure: Cyclone Head Blower

Procedure of R03



DOE of R03

Table: Excerpt of Pin Material Study DOE

Material	Ring gap	Paddle Shaft RPM	Drum RPM
Steel	0.43	630	28
Steel	0.47	518	31
Steel	0.49	645	34
Steel	0.39	798	26
Steel	0.44	414	31

- Each material has **five** runs of experiments
- Intact Halves was the only dependent variable

Results of RO3

Table: ANOVA Test

Variable	df	SS	MSE	F-Statistics	P-value
Material	4	0.049	0.012	5.449	0.005
Ring gap	1	0.090	0.090	40.339	0.000005
Paddle Shaft RPM	1	0.181	0.181	80.353	0.00000005
Residual	18	0.040	0.002	NaN	

- All independent variables were significant
- Paddle shaft RPM has the most significant impact with intact halves
- Neither processing time nor discharge throughput were recorded

Results of RO3 (Cont.)

Table: OLS Regression

Variable	Coef	Std Error	t	P>|t|
Intercept	0.3485	0.192	1.818	0.086
Aluminum	0.0010	0.033	0.030	0.976
Half-length Steel	0.1006	0.030	3.352	0.004
Nylon	0.0273	0.031	0.882	0.389
Polyethylene	0.0671	0.031	2.169	0.044
Ring Gap	1.0886	0.394	2.766	0.013
Paddle Shaft RPM	-0.0005	5.55e-05	-8.964	0

- Standard steel pin was the baseline of the analysis
- Half-length Steel and Polyethylene demonstrated the most significant impact
- Adj R-Squared = 0.850

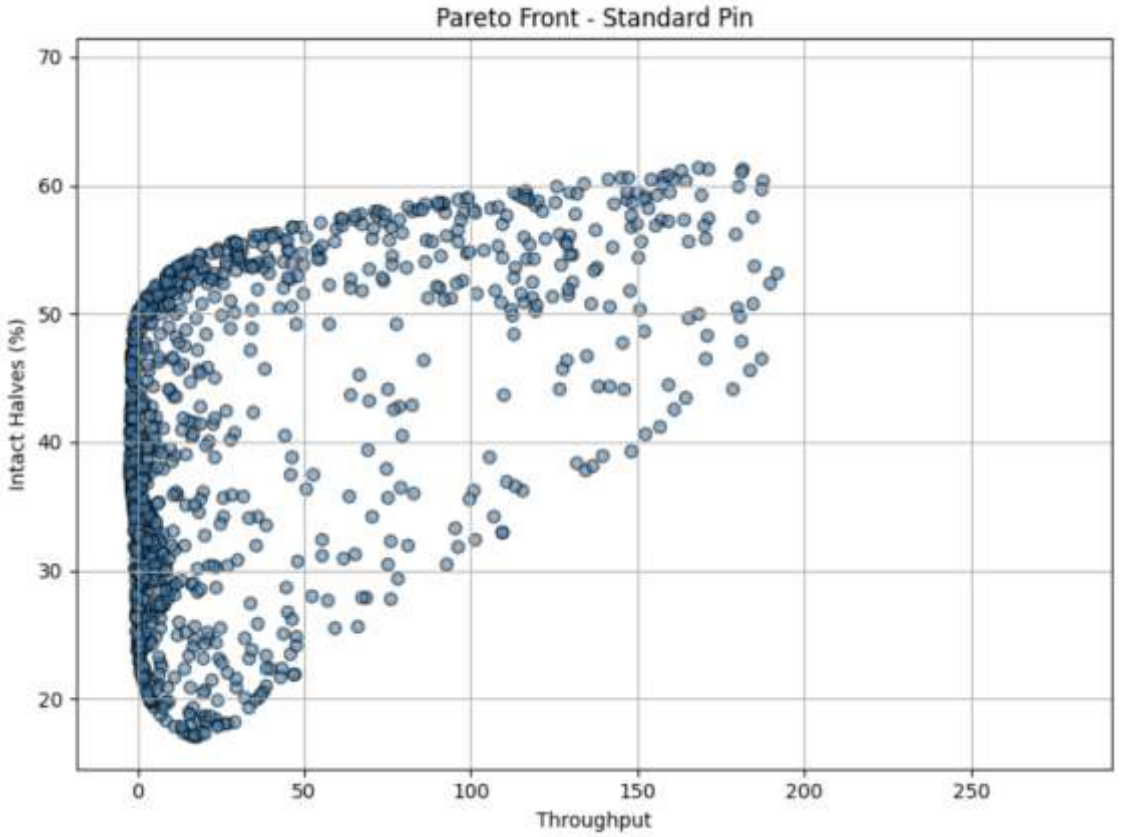
DOE of R03

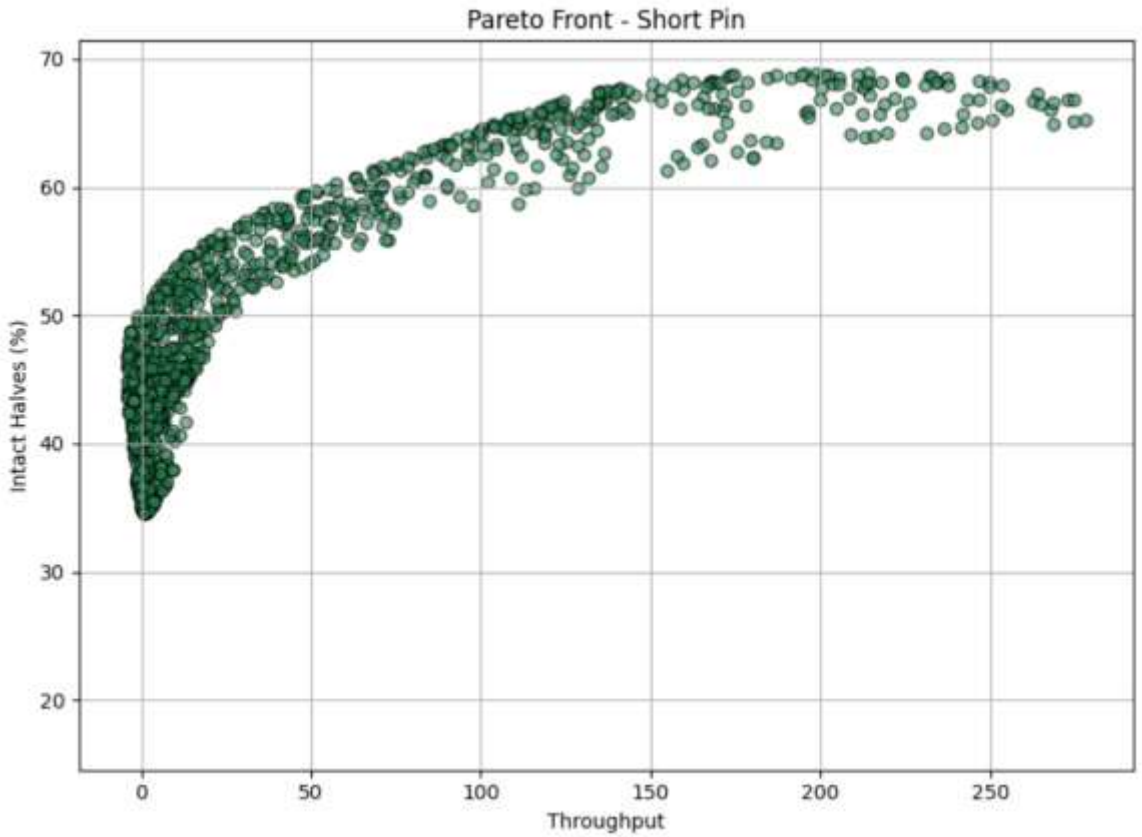
Table: Excerpt of Pin Length Study DOE

Material Length	Ring gap	Paddle Shaft RPM	Drum RPM
Standard Pin	0.49	776	30
Standard Pin	0.45	553	30
Standard Pin	0.47	858	30
Standard Pin	0.44	1008	30

- Each pin length has **ten** runs of experiments
- Three dependent variables were recorded: intact halves, discharge throughput, processing time

Length Results





Gradient Configuration

Uniform Configuration

Length Results

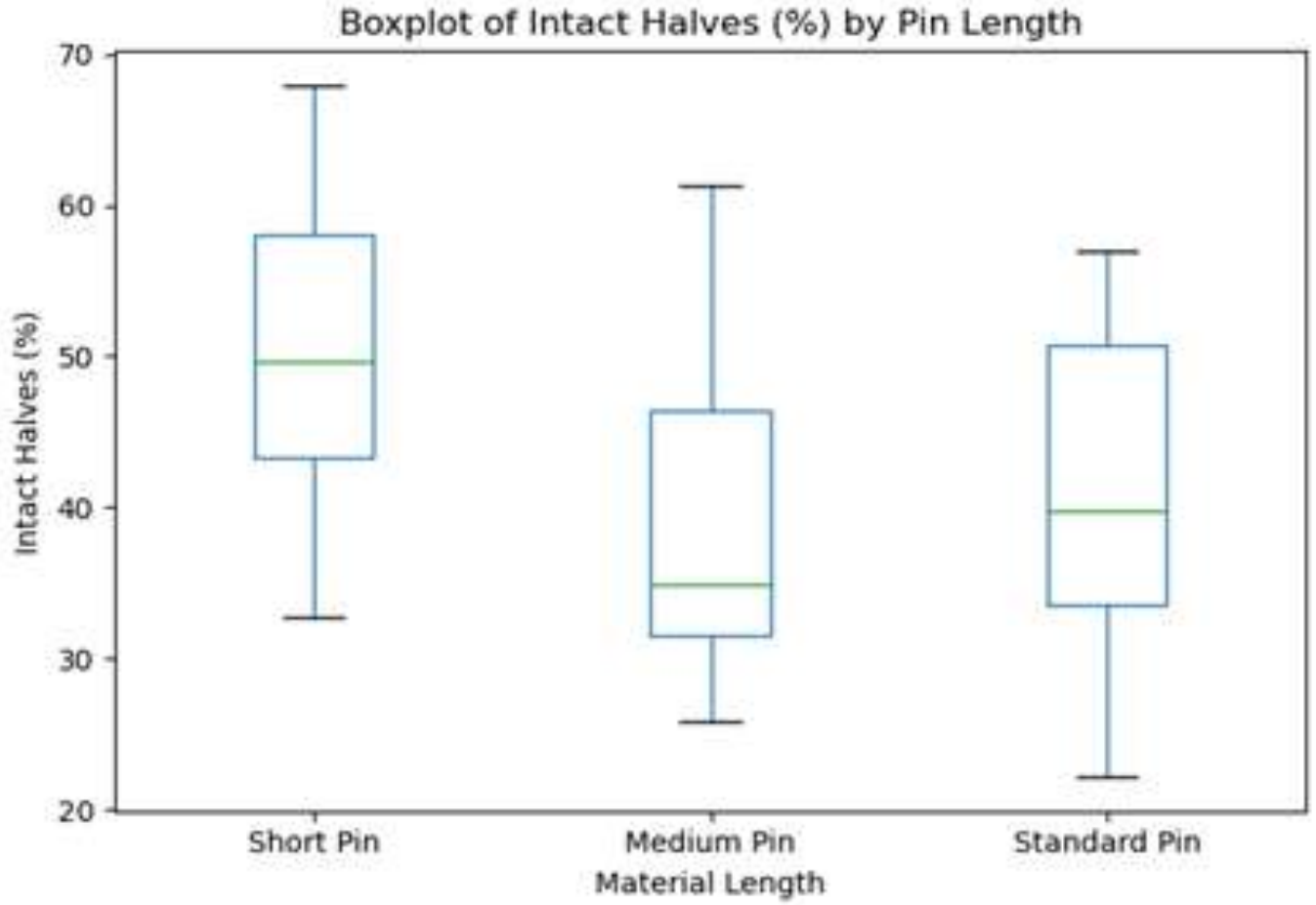


Figure: Intact Halves Vs Pin Length

Length Results

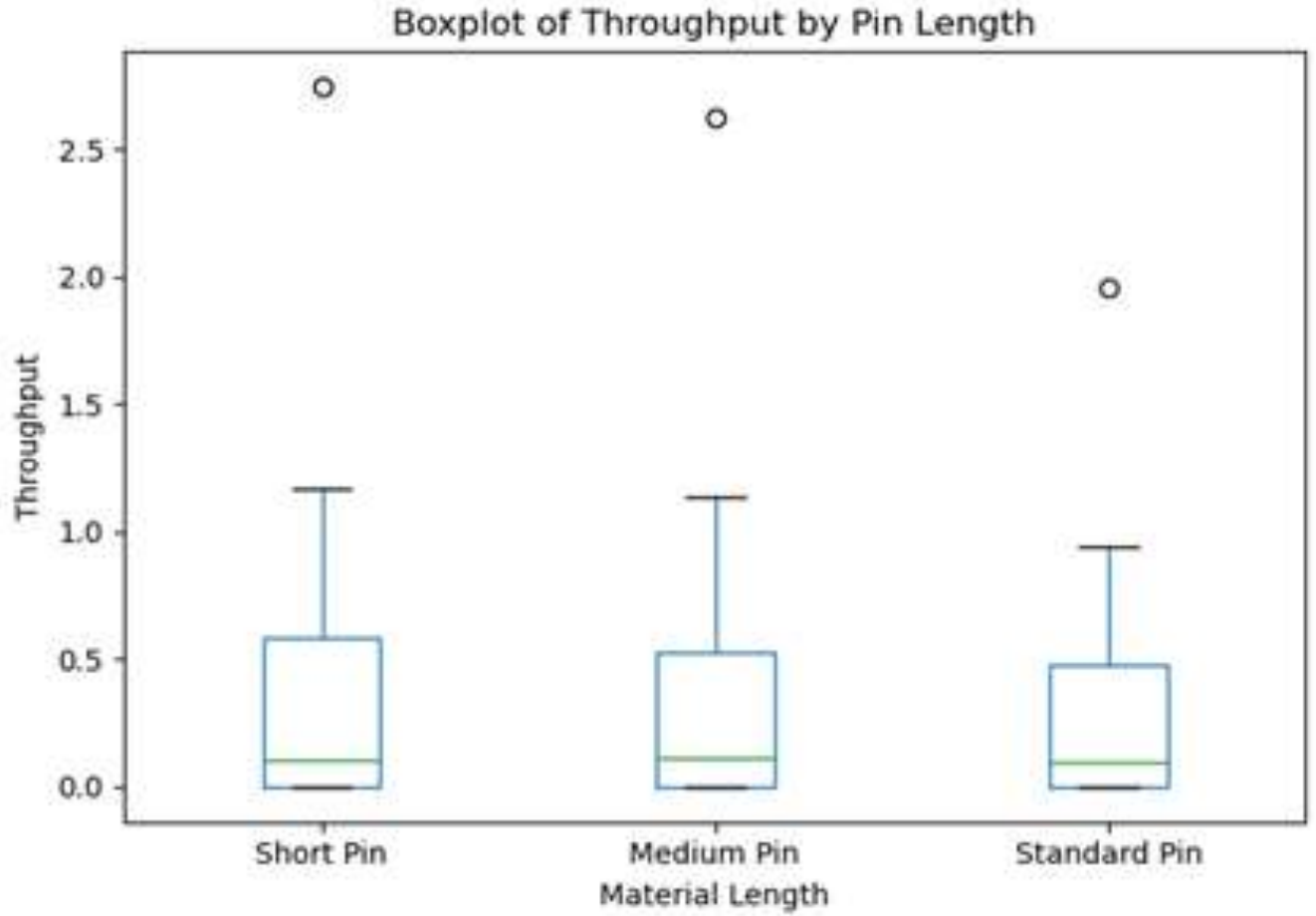


Figure: Throughput Vs Pin Length

Length Results

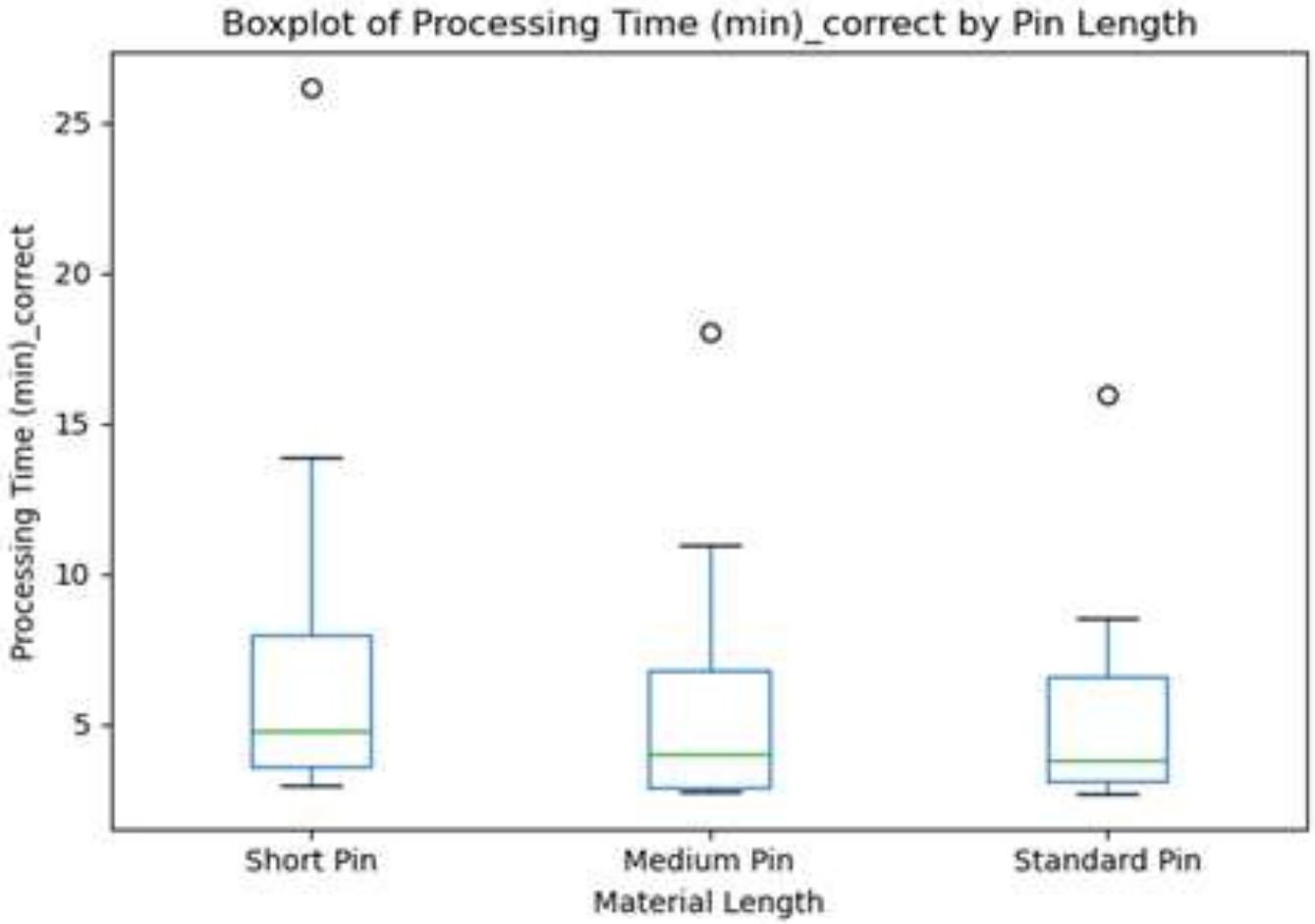
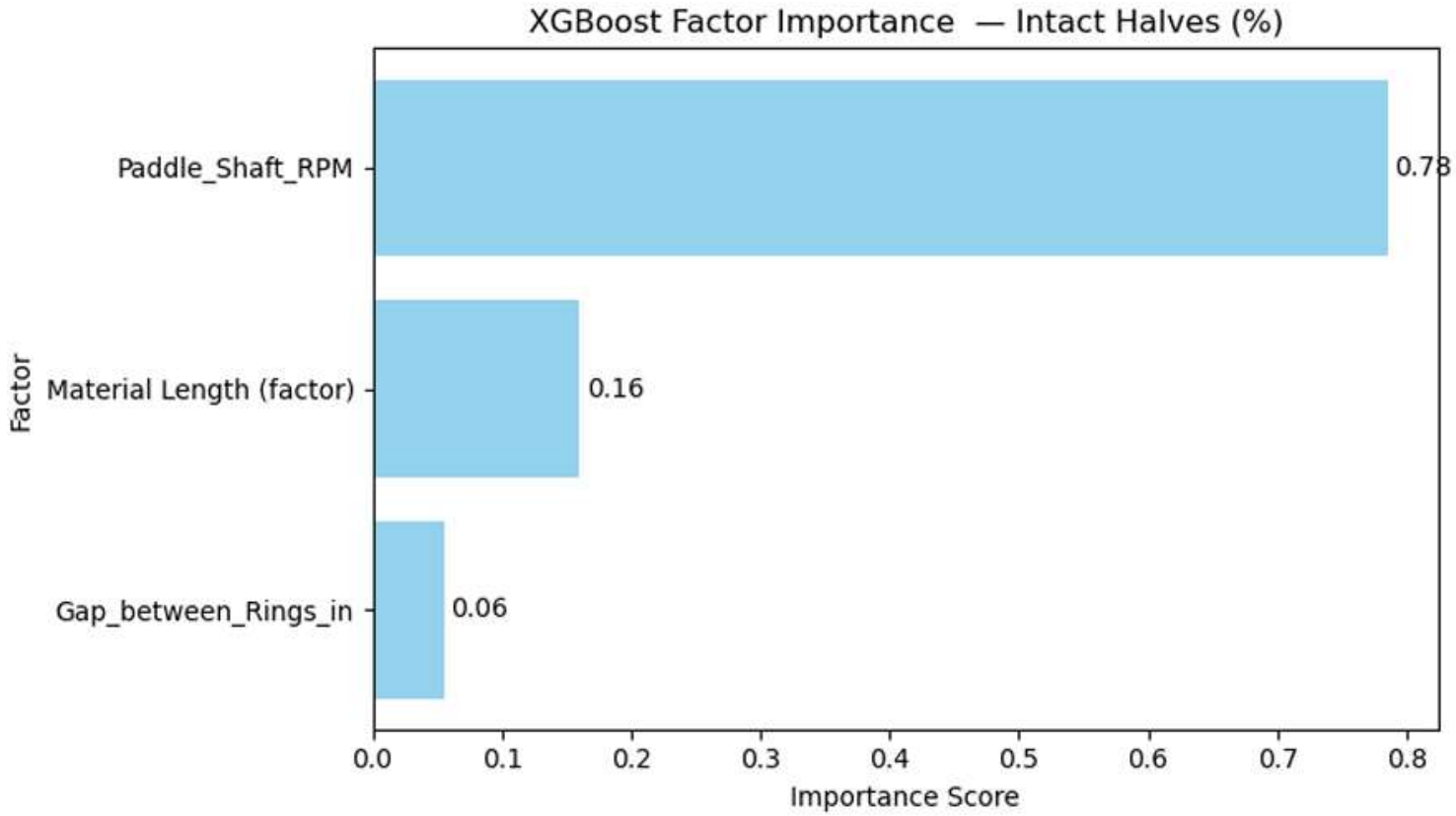


Figure: Processing Time Vs Pin Length

Pin Length Optimization



RO3 Recommendations

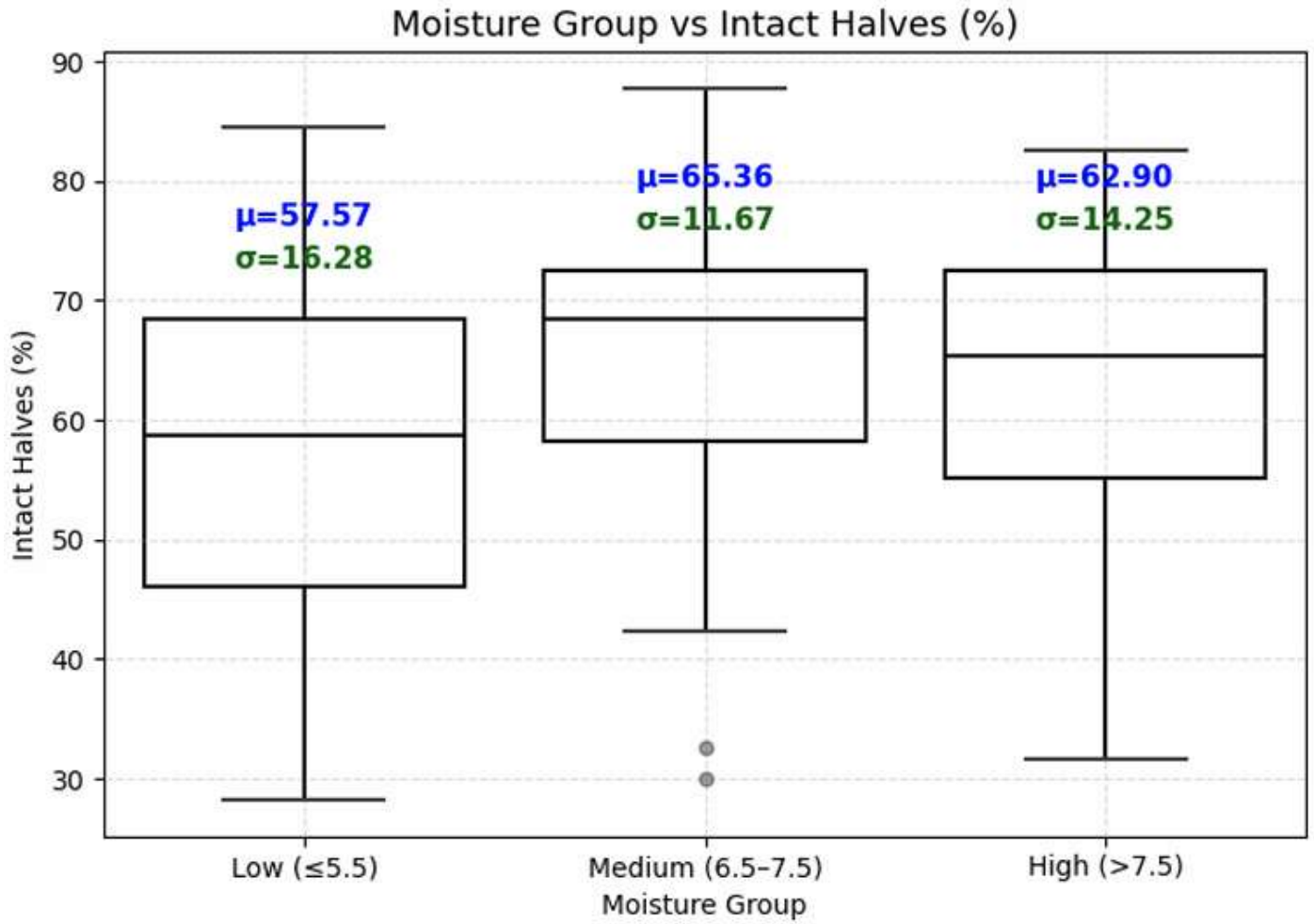
- Pin length has a significant impact on half yield
- Uniform paddle shaft yields a higher half yield than the paddle shaft with a gradient
    - Without significantly increasing processing time or discharge (%)
- Within uniform configurations, shorter paddle shaft pins contribute to higher half-yield

Summary

- Paddle Shaft RPM and Ring Gap are the only significant machine factors affecting half yield
- Increasing moisture improves the half yield in a controlled environment
- Combination of maximized Ring Gap and moisture, minimized Paddle Shaft RPM, and a short-pinned uniform paddle shaft will yield the highest half-yield

**Final parameter selection will depend on specific facility configurations and priorities.*

Moisture Effects on Half- Yield



Sensitivity Analysis		Intact Halves (%)	Discharge Throughput (lbs. %)	Intact Halves (%)	Discharge Throughput (lbs. %)	Intact Halves (%)	Discharge Throughput (lbs. %)	Intact Halves (%)	Discharge Throughput (lbs. %)	Intact Halves (%)	Discharge Throughput (lbs. %)
		Importance Weight		Importance Weight		Importance Weight		Importance Weight		Importance Weight	
		9	1	8	2	7	3	6	4	5	5
		Obtained Values		Obtained Values		Obtained Values		Obtained Values		Obtained Values	
Machine Settings	Gap between Rings (in)	0.456		0.461		0.463		0.465		0.466	
	Tilt Angle (θ)	2.5		2.5		2.5		2.5		2.5	
	Paddle Shaft RPM	400		484.848		549.54		597.980		634.34	
	Drum RPM	31.16		31.061		30.96		30.65		30.35	
	Moisture Level (%)	9		9		9		9		9	

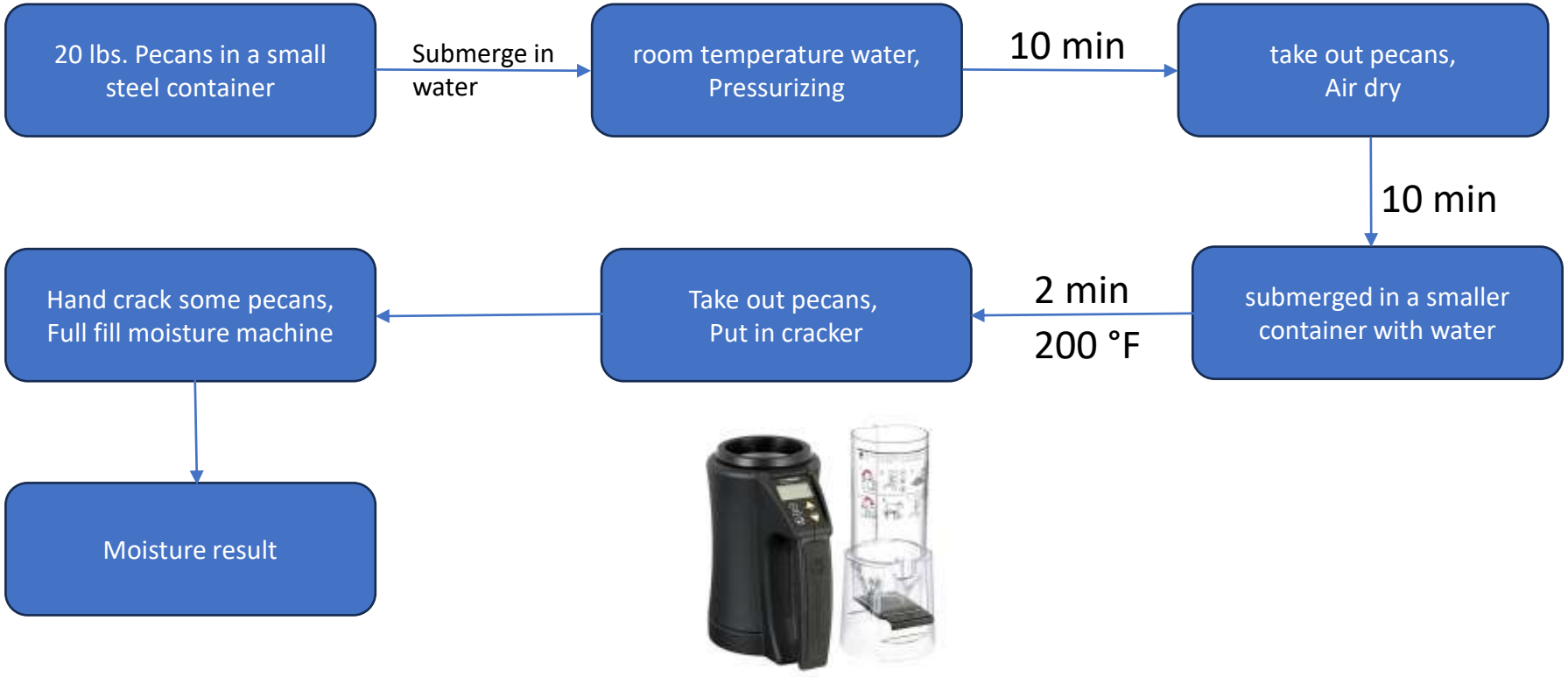
Pin Material Property Results – extra slide

Table: ANOVA Test

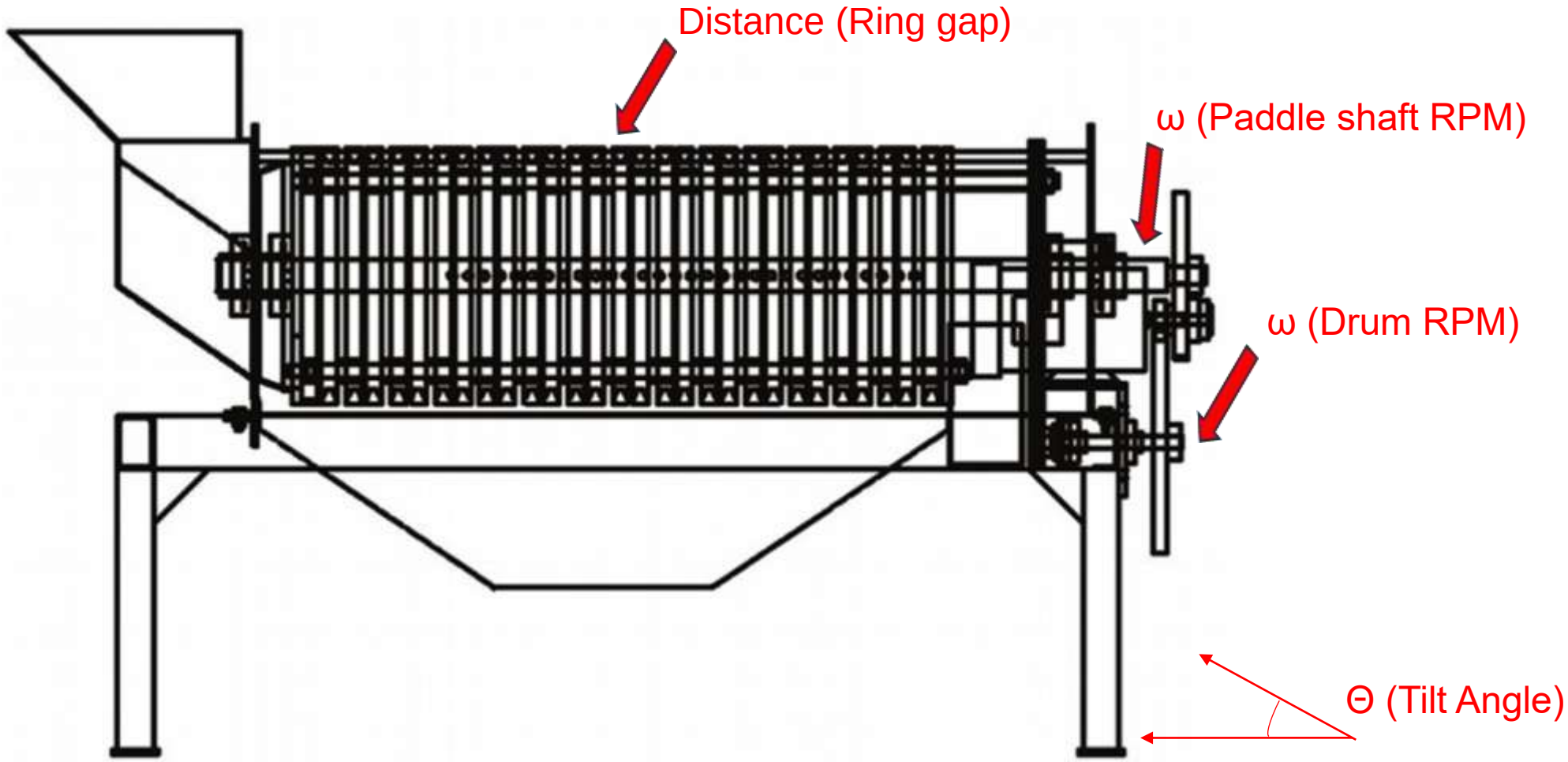
Variable	df	SS	MSE	F-Statistics	P-value
Length	1	0.041	0.041	18.088	4.784669e-04
Young's Mod	1	0.0009	0.0009	0.430	5.200443e-01
Yield Strength	1	0.007	0.007	3.276	8.704684e-02
Tensile Strength	1	0.000009	0.000009	0.004	9.513408e-01
RingGap	1	0.091	0.091	40.339	5.532785e-06
Paddle Shaft RPM	1	0.181	0.181	80.353	4.674908e-08
Residual	18	0.041	0.002	NaN	NaN

- Only Length was significant among all properties

Moisture Procedure for R03



Design of Experiments



Thank you!

Questions & Comments