


STEAMS Approach: Preparing the Freshest Steamed Dumplings

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Project Charter

STEAMS
STEM to STEAMS

Problem Statements

- Most foods like dumplings are made without precise control of cooking parameters
- Dumpling “taste” may be adversely affected by improper cooking time
  - Taste considers factors such as crispiness and firmness, which is linked to cooking time
- Sooner or later, A.I. and robotics will be an important part of the food industry
  - COVID-19 has highlighted and likely accelerated the need for this

Project Objectives

- Use thermal physics, A.I. Modelling, and Automation to standardize the cooking procedure
- Adjust the model until it can accurately predict time needed to cook dumplings based on given inputs
- Minimize human interaction in the preparation of dumplings through cooking method and production method

Why Dumplings?

STEAMS
STEM to STEAMS

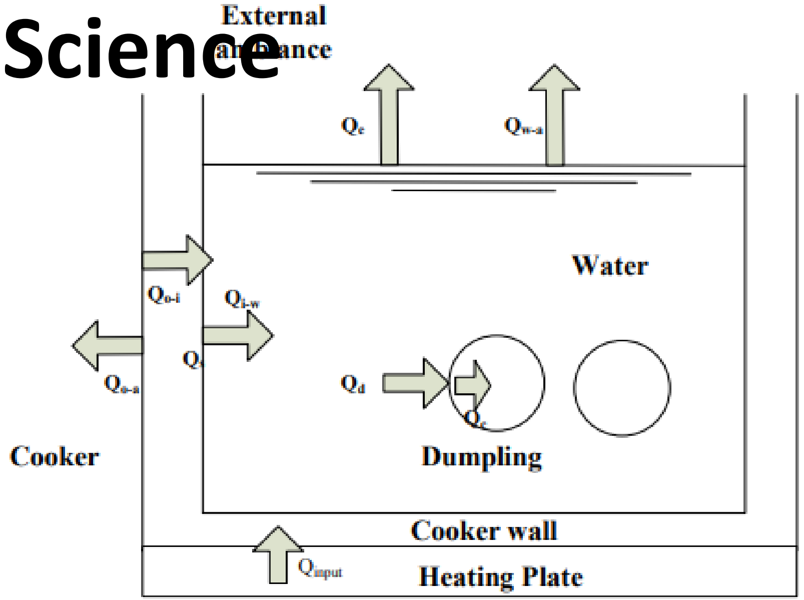
Utility as a food for the COVID-19 Era

- They are easy to cook
- The method of cooking (namely boiling) kills foreign particles that might be living on it
- There is little human interaction in the cooking of dumplings, so risk of spread is much lower

Design & Process space that is intuitive and extendable

- Consider familiar physical problem involving heat transfer physics.
- Consider familiar process parameters such as time, temperature, mass.
- Consider familiar hand-held measurement equipment subject to typical sources of repeatability and reproducibility variation.

Science: Heat Transfer Physics and Food Science

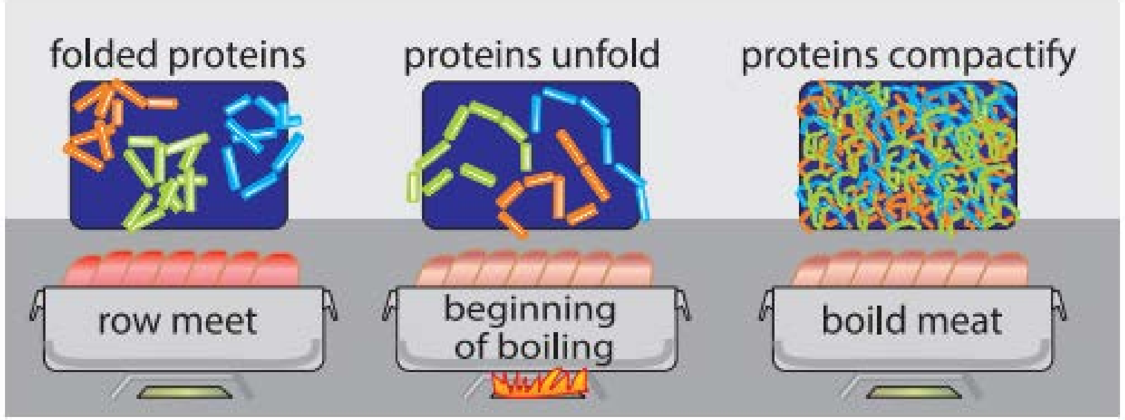


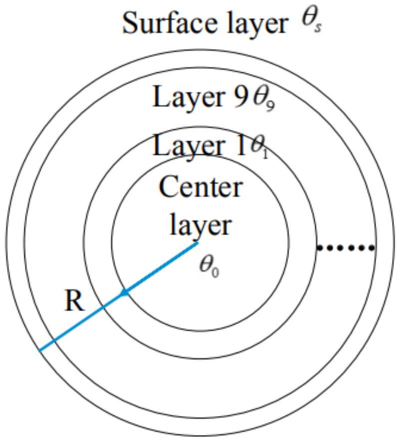
Simplified model, thickness of slap delta-t

$$q = \Delta Q / A \Delta t$$

Spherical model, r = radians, k = heat transfer coefficient

$$q(R,t) = -\kappa \left[\frac{\partial T(r,t)}{\partial r} \right]_{r=R}$$





$$\frac{d\theta_0}{dt} = 300 \frac{\alpha_d}{R^2} (\theta_1 - \theta_0)$$

Thermal Conduction energy transfer in the form of thermal energy (heat) goes from the cooker wall into the water.

Natural Convection water boiling generates cavitation bubble collapse and turbulent flow, creating heat energy gradients.

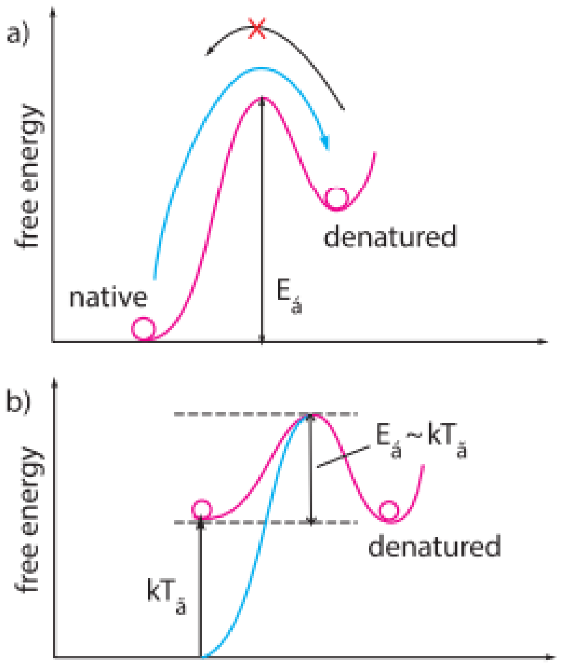
Diffusion energy transfer in the form of thermal energy (heat) goes into the dumpling mass, changing the configuration of the meat proteins.

Technology: Cooking Method and Process Monitoring

1. **Boiling Cooker:** Composition of cooking vessel (metal vs stone), energy delivery method (electric vs gas).

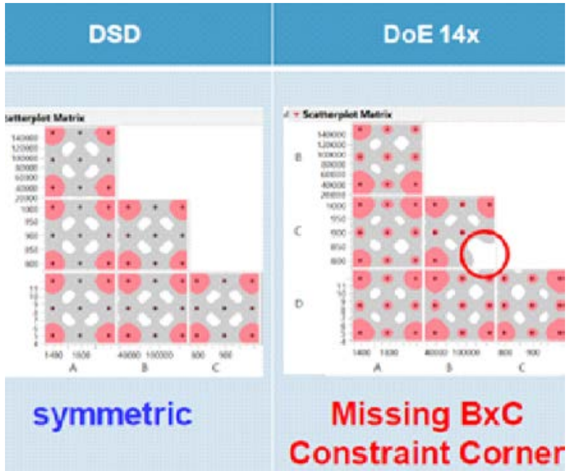
1. **Temperature/Time Regulation**: Cooking medium temperature regulation by Infrared (IR) and time by digital timer.

1. **Dumpling Composition**: Composition controlled by weighing balance.



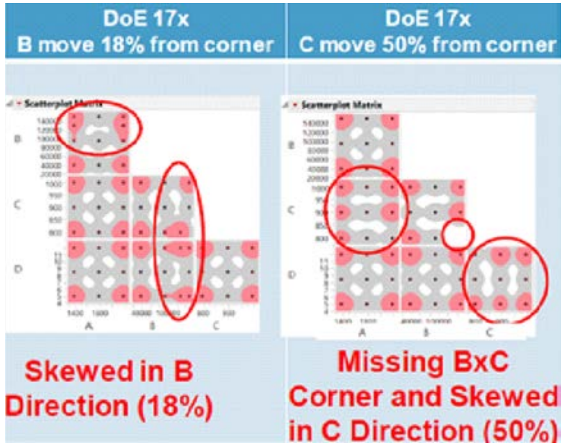
Engineering: Experimental Setup/Design/Execution

Phase I: Decide on Tools (Balance Scales, Utensils, Cooking Pots, Mixing Bowls). Consider equipment accuracy/ precision as applicable)



Phase 2: Dumpling Assembly Process Line Layout, including headcount allocation and utilization (takt) among each cook & master Chef.

Phase 3: DSD DOE – Optimal Orthogonality, Power, and Uniformity



Phase 4: Proper experimental execution: Preparing the dumplings to the indicated experimental settings, measuring/recording the response (cooking time).

Phase 5: Analysis and effective interpretation of data in JMP, summary of results, conclusions, and next steps.

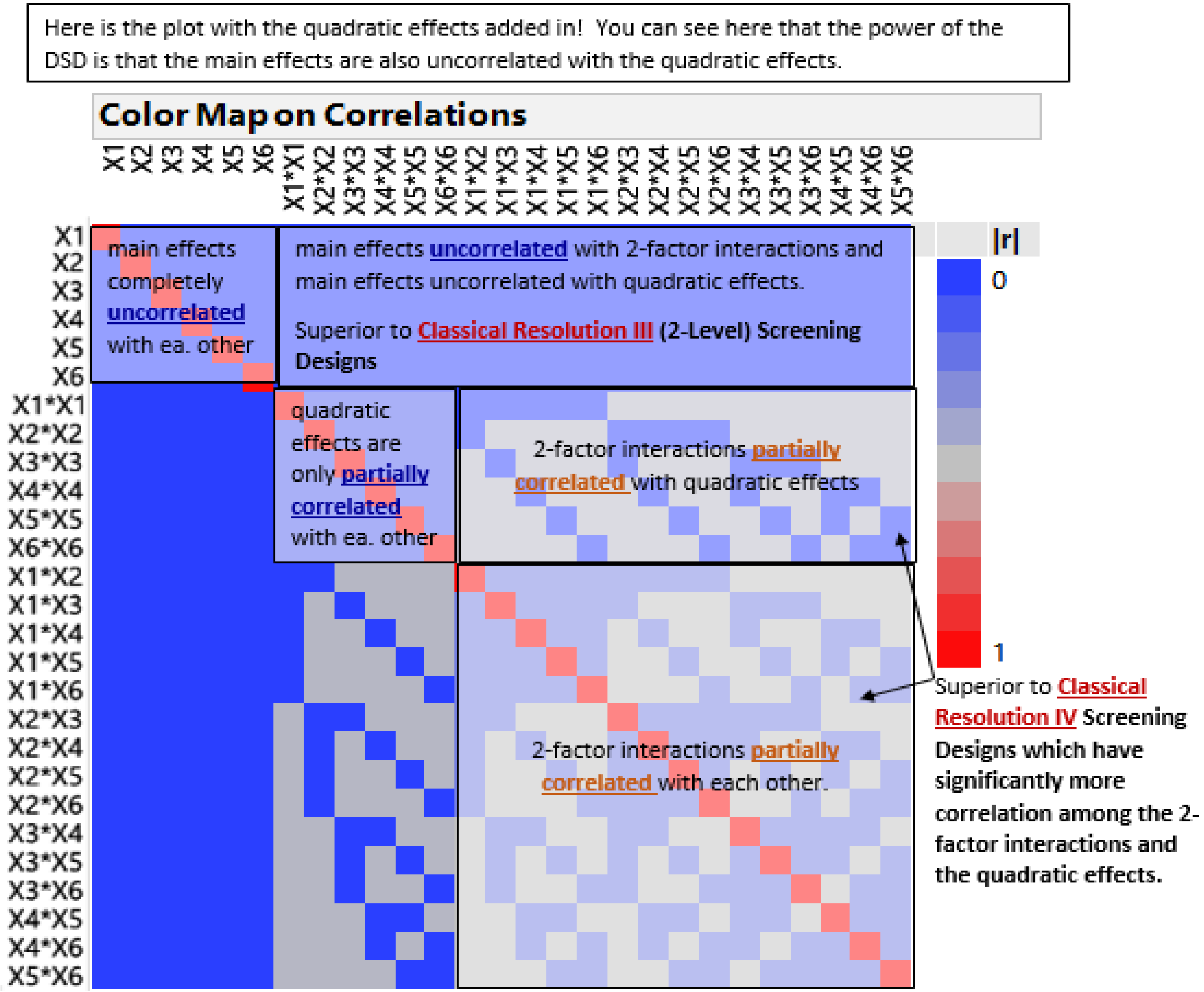
Engineering: Data Collection Plan

- Collect Information on: Meat Type, Meat Mass, Veggie Mass (Cabbage/Mushroom), Total Dumpling Mass, Batch Size, Water Temp.
- Collect 18 DSD runs and measure the response – Rising Time.

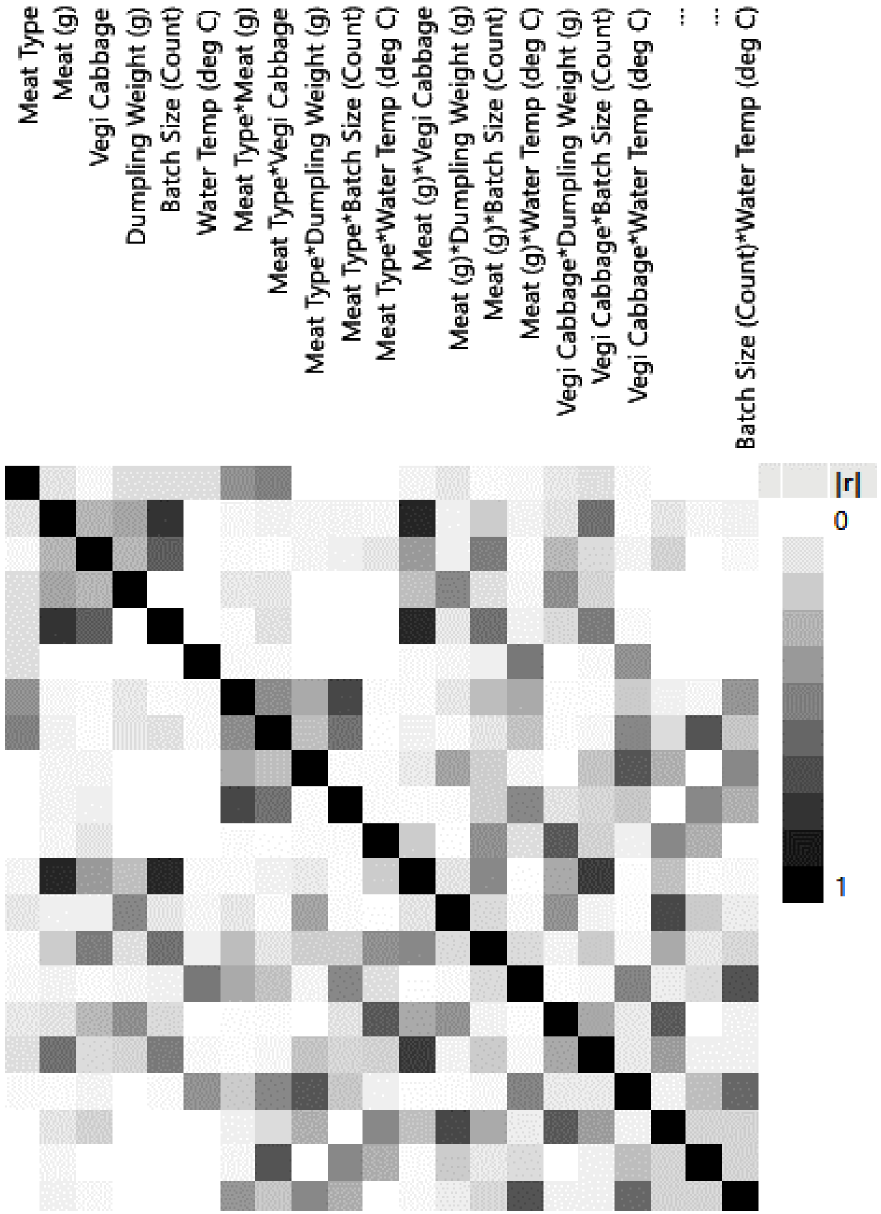
Run No.	Randomized Run No	Ratio (meat%)	Meat Type	Meat (g)	Vegi Cabbage (g)	Vegi Mushroom (g)	Dumpling Weight (g)	Batch Size (Count)	Water Temp (deg C)	Dumpling Rising Time (min:s)
1	9	0.8	Pork	80	16	4	25	4	95	1:21
2	11	0.8	Shrimp	140	28	7	25	7	75	3:20
3	18	0.5	Shrimp	125	100	25	25	10	95	0:55
4	16	0.5	Shrimp	34	27.2	6.8	17	4	85	0:50
5	2	0.65	Pork	110.5	47.6	11.9	17	10	95	1:20
6	1	0.5	Pork	125	100	25	25	10	75	7:36
7	12	0.5	Shrimp	50	40	10	25	4	95	1:05
8	3	0.5	Pork	59.5	47.6	11.9	17	7	95	1:10
9	17	0.65	Shrimp	95.55	41.2	10.3	21	7	85	1:38
10	15	0.8	Shrimp	168	33.6	8.4	21	10	95	2:04
11	13	0.65	Shrimp	65	28	7	25	4	75	5:19
12	4	0.65	Pork	95.55	41.2	10.3	21	7	85	3:27
13	5	0.8	Pork	200	40	10	25	10	85	2:25
14	6	0.5	Pork	42	33.6	8.4	21	4	75	2:01
15	14	0.8	Shrimp	54.4	10.9	2.7	17	4	95	0:46
16	7	0.8	Pork	136	27.2	6.8	17	10	75	2:42
17	8	0.8	Pork	54.4	10.9	2.7	17	4	75	1:59
18	10	0.5	Shrimp	85	68	17	17	10	75	1:52

Statistics: Definitive Screening Designs (DSD)

- DSD: Definitive Screening Design
  - Fold-over pairing is exploited in order to reduce your sample size (does all corner pairing to increase Power and orthogonality).
- **<u>Properties of DSDs:</u>**
- Small number of DOE runs
- Main effects Orthogonal (No Resolution II Confounding)
- Main effects uncorrelated with 2-way Interactions (No Resolution III Confounding)
- 2-Way Interactions are not fully confounded with each other (Resolution IV Confounding)
- Estimable quadratic effects – in a three level design (Non-Linear)

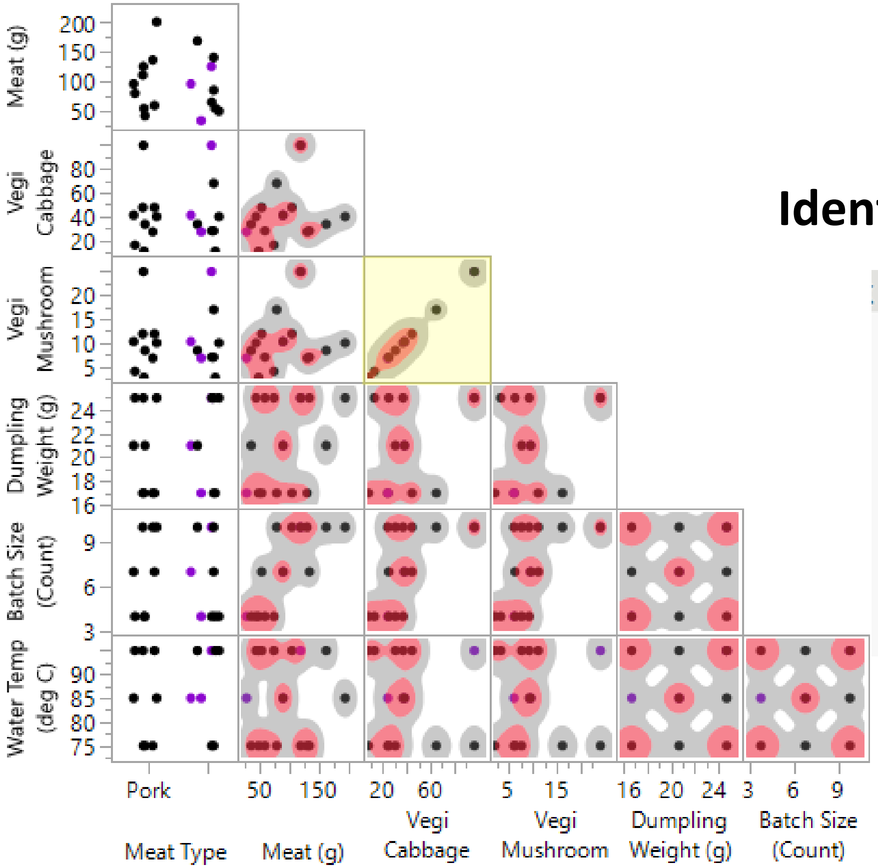


Statistics: Design Diagnostics



Observed certain Confounding:

- Resolution II: Batch Size with Meat (g)
- Resolution III: Meat (g) with Meat (g)* Vegi (Cabbage)
- Confounding associated with one Design Constraint:
  Meat + Vegi (Cabbage)+ Vegi (Mushroom)= Dumpling Weight



Identified 6 Independent Variables

Entered	Parameter
✓	Intercept
✓	Meat Type{Shrimp-Pork}
✓	Meat (g)
✓	Vegi Cabbage
✓	Dumpling Weight (g)(17,25)
✓	Batch Size (Count)(4,10)
✓	Water Temp (deg C)(75,95)

Statistics: Stepwise Regression Goodness of Fit

Stepwise Regression Model showed very good goodness-of-fit (GoF).

Effect Summary

Source	LogWorth	PValue	
Meat (g)*Water Temp (deg C)	2.527	0.00297	
Meat Type	2.511	0.00308	
Meat Type*Vegi Cabbage	2.502	0.00315	
Dumpling Weight (g)*Dumpling Weight (g)	2.488	0.00325	
Batch Size (Count)*Water Temp (deg C)	2.426	0.00375	
Vegi Cabbage*Water Temp (deg C)	2.354	0.00443	
Meat (g)*Batch Size (Count)	2.184	0.00654	
Dumpling Weight (g)(17,25)	1.919	0.01204	^
Water Temp (deg C)(75,95)	1.899	0.01263	^
Meat (g)*Meat (g)	1.858	0.01387	
Dumpling Weight (g)*Water Temp (deg C)	1.844	0.01431	
Vegi Cabbage*Dumpling Weight (g)	1.827	0.01489	
Vegi Cabbage	1.736	0.01837	^
Batch Size (Count)(4,10)	1.698	0.02004	^
Meat (g)	1.663	0.02171	^
Water Temp (deg C)*Water Temp (deg C)	1.530	0.02952	

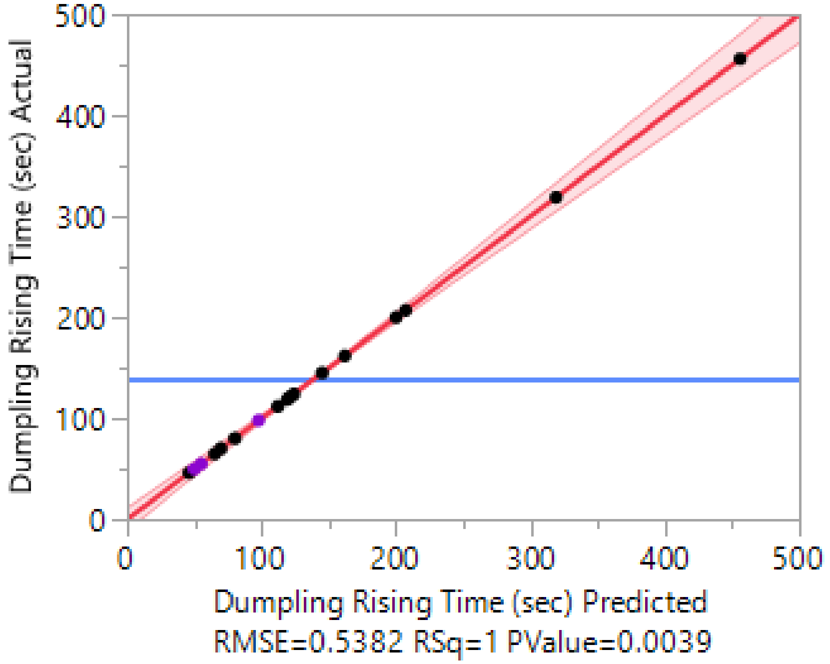
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	16	185862.15	11616.4	40105.68
Error	1	0.29	0.289644	Prob > F
C. Total	17	185862.44		0.0039*

Summary of Fit

RSquare	0.999998
RSquare Adj	0.999974
Root Mean Square Error	0.538186
Mean of Response	139.4444
Observations (or Sum Wgts)	18

- Iterative procedure with an inexact solution.
- Significant overfit risk



Model coefficients explain >99% of the variability in Rising Time.

Statistics: Main Effect and Interaction Effect

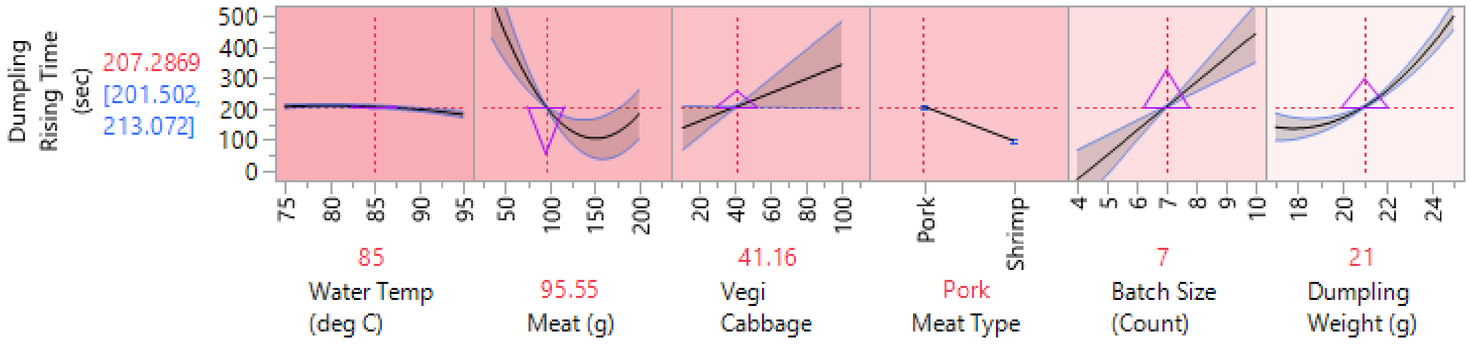
- Observed Significant Interaction Effects
- Due to previous Design Constraint, the DSD DOE was not well structured. The observed interactions may be due to competing physics and/or alias structure.
- Top four parameters are: **(1) Water Temp**, **(2) Meat,** (3) **Vegi Cabbage**, (4) **Meat Type** (Shrimp or Pork). Batch Size is less important which may indicate the heat transfer was quite uniform and least impacted by Batch Size. Dumpling Weight was aliased with Meat and Vegi.

Summary Report

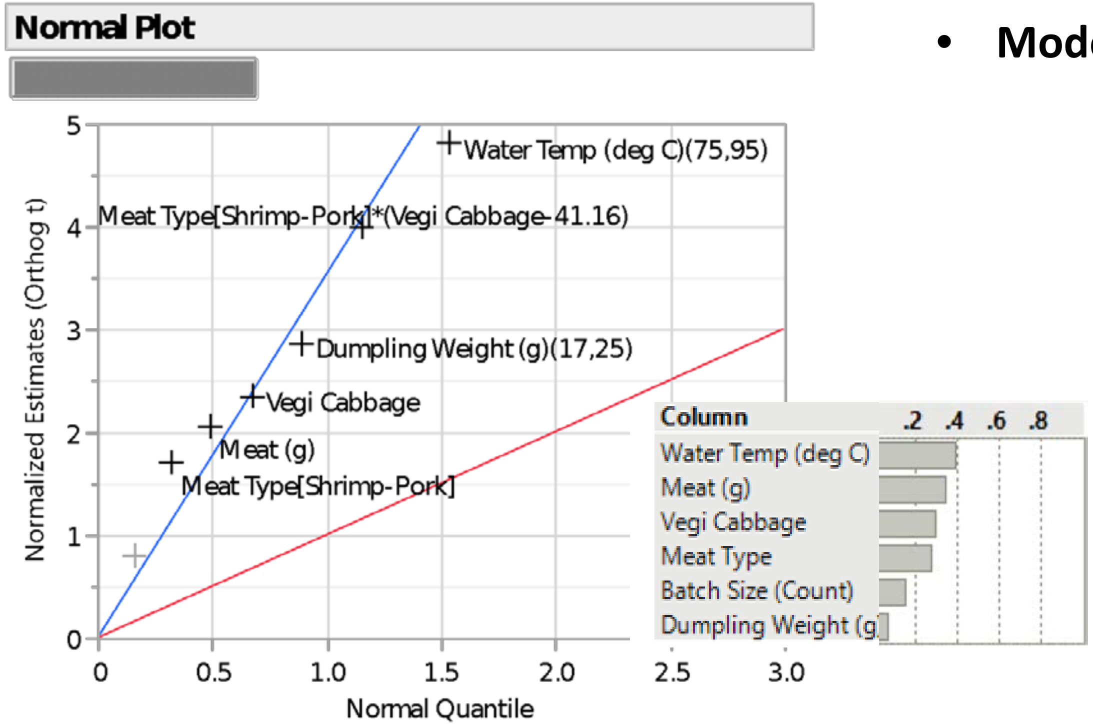
Column	Main Effect	Total Effect	Total Effect-Main Effect
Water Temp (deg C)	0.106	0.397	0.291
Meat (g)	0.081	0.349	0.268
Vegi Cabbage	0.091	0.304	0.213
Meat Type	0.127	0.28	0.153
Batch Size (Count)	0.032	0.16	0.128
Dumpling Weight (g)	0.059	0.069	0.010

Pareto Plot of Transformed Estimates

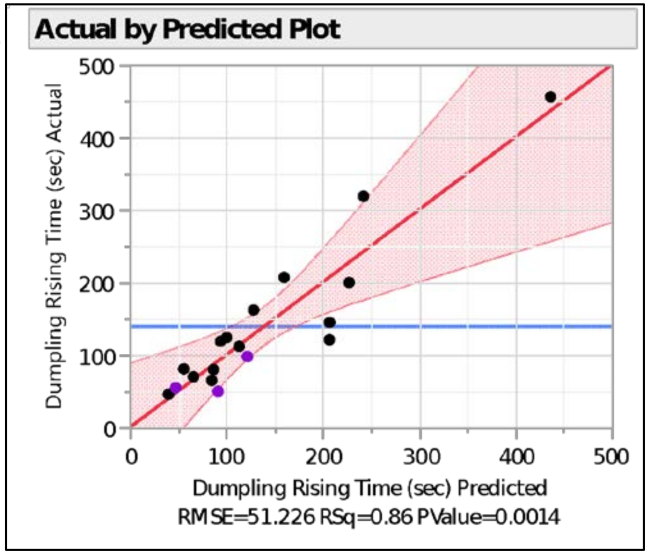
Term	Orthog Estimate
Water Temp (deg C)(75,95)	-58.22628
Meat (g)	-48.30165
(Meat (g)-95.55)*Water Temp (deg C)	34.58808
Vegi Cabbage	28.43649
Meat Type[Shrimp-Pork]*(Vegi Cabbage-41.16)	24.86501
Meat Type[Shrimp-Pork]	-20.66667
Dumpling Weight (g)(17,25)	9.70467



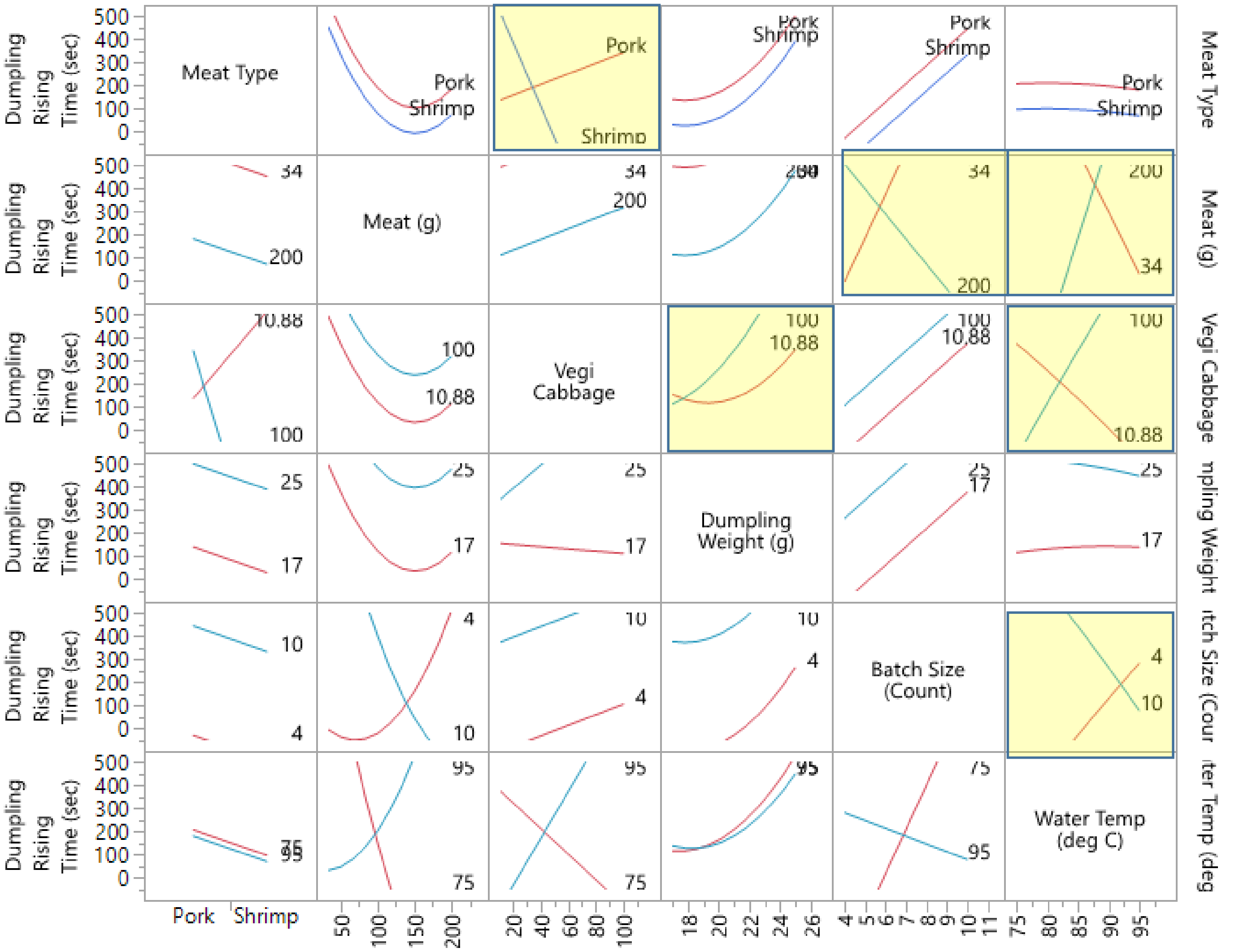
Statistics: Reduced model



Blue line has slope equal to Lenth's PSE.
Red line has slope 1.

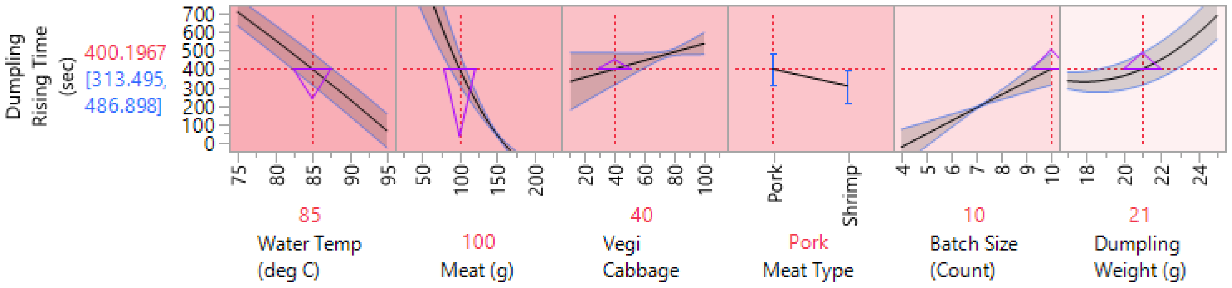


- **Model Fit from DSD Design with RSM Structure**

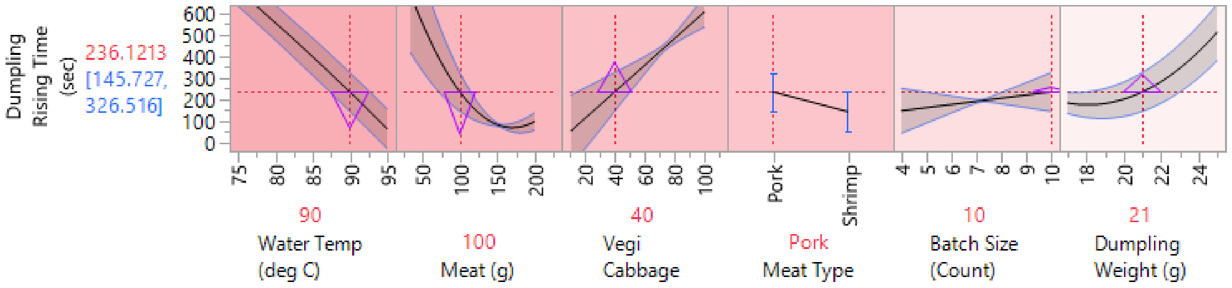


Statistics: Prediction Profiler

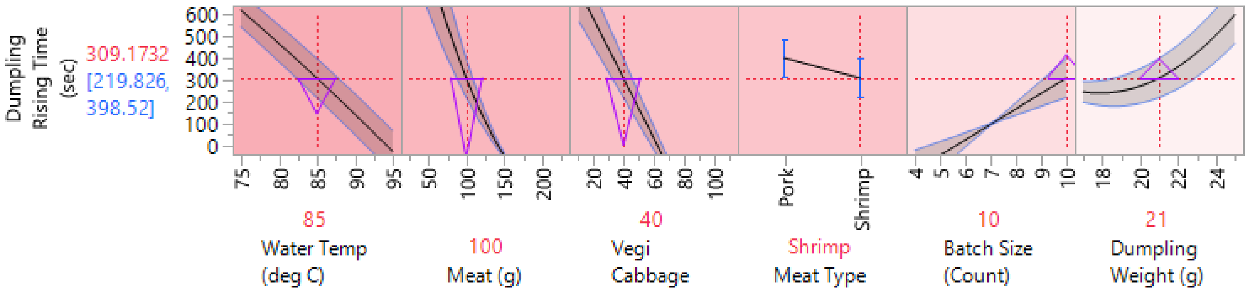
Case I (Default): Cooking time ~ 400 +/- 87 Seconds



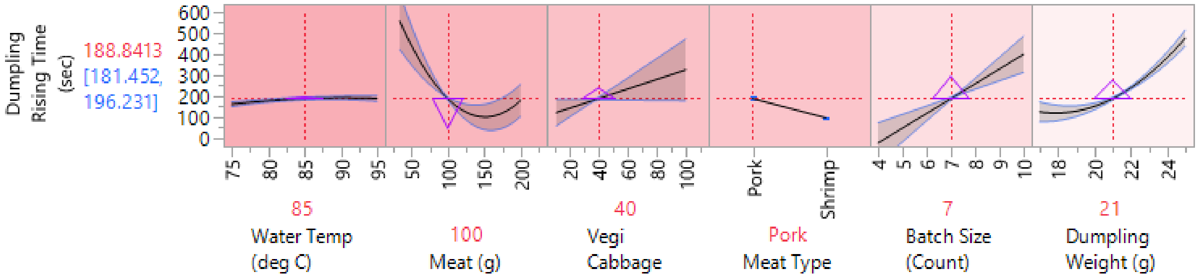
Case II (Temp=92): Cooking time ~ 236 +/- 100 Seconds



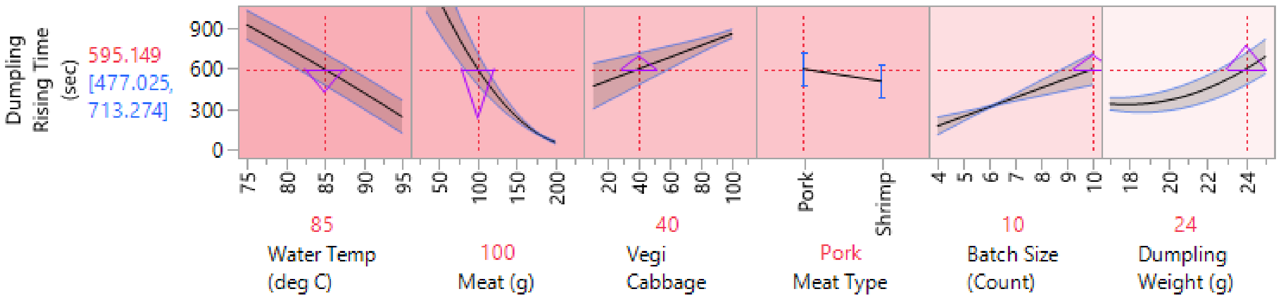
Case III (Shrimp): Cooking time ~ 309 +/- 89 Seconds



Case IV (Batch=7): Cooking time ~ 189 +/- 7 Seconds



Case V (Dumpling Weight=24): Cooking time ~ 595 +/-118 Seconds



How to Optimize Cooking Process:

- Faster Time
- Lower Variance in Duration
- Max Throughput
- Power Saving

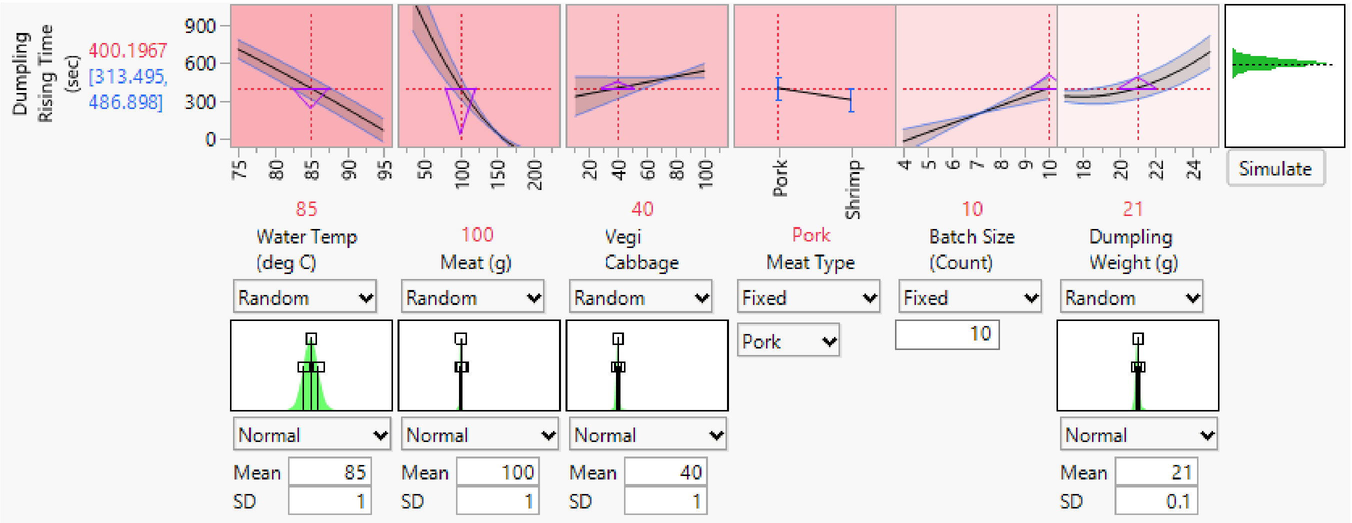
Engineering: Optimize Dumpling Process

How to Optimize Cooking Process:

- Faster Rising Time
- Lower Variance in Duration
- **Max Throughput**
- **Power Savings**
- **Monte Carlo Simulation**

$$\text{Batch Size (Count)} \cdot \left(\frac{\text{Dumpling Weight (g)}}{\text{Dumpling Rising Time (sec)}} \right)$$

$$\text{Water Temp (deg C)}^2 \cdot \text{Dumpling Rising Time (sec)}$$



Consider HACCP Control windows and Measurement Device Capability.

Engineering: HACCP and ISO 22000

	Function	Variables	Leader	Member	CCP	Validation	Monitoring	Verification
A	Prepare Vegi Ingradient	Dry Duration	Sean	Alan	Container Labeling	Define how to cut vegi	Vegi Container Labeling	Dry all vegi pieces
B	Mix, Stir (2 meat x 2 vegi x 3 ratios)	1.Meat, 2.Vegi, 3. Ratio (25%, 50%, 75%)	Leo/Matt	Kathy's Boy	Weight Ratio +/- 1%	Weight Tolerance +/1 gram	Check Meat/Vegi Ratio	Visual Inspection on Ratio/Stir Efficiency
C	Dumpling Weight (3) X Pi Type (2)	4. Weight (20, 25,30),5. Pi	Kathy	Kathy's Daughter	Dumpling Weight +/- 0.5gm	Weight tolerance within +/-0.1 gram	Pi Type Labeling	Meet Dumpling Weight Target within +/-0.5 gram
D	Make Dumplings (Shape, Number)	6. Shape/Maker, 7. Batch Size (5,10,15)	Julianne's Mom	Julianne	Zero Tolerance on the Batch Size	Trainging between two Dumpling Makers	Count the Number of Dumpings	Any broken Dumpling (record how many)
E	Cooking (Water Temp)	8. Initial Water Temp (75C, 85C, 95C), 9. Pan Size (Water Depth)	Christina	Brianna	Control Water Temp +/- 2C?	Define Infrared Measurement	Take Multiple Readings every 30 seconds?	Check Dumplings are fully cooked
F	Dumpling Duration (Rising time)	3 more mins after last piece rised up?	Allan	Julianne's Sister	Rising up time within 0.3 second between two operators	Measure the Pan Contact Area of the Bottom Surface	Count the duration of the last one rising up	Check all Dumplings are fully cooked
G	Traveller	Define Traveller Template or use Laptop	Mason	Charles	No Missing or typo Information	All A-F Categories are listed	Traveller with each Dumpling Plate Treatment	Check all informaiton filled by each Group Leader
H	JMP Data Entry		Patrick	JeAnne	No Typo on Data Entry	Create JMP DSD Datasheet	Check all information available on the traveller	Double Check the Data Entry (no trpo or missing)

- Introduction to HACCP: https://www.slideshare.net/Adrienna/introduction-to-haccp-57715003
- HACCP Description Chart: https://www.researchgate.net/figure/HACCP-DESCRIPTION-CHART_tbl5_260401936

Mathematics: Monte Carlo Robust Design Simulation

Summary Report

Overall

Column	Main Effect	Total Effect
Meat (g)	0.2	0.463
Vegi Cabbage	0.112	0.338
Batch Size (Count)	0.183	0.237
Water Temp (deg C)	0.044	0.147
Meat Type	0.049	0.112
Dumpling Weight (g)	0.047	0.063

Dumpling Rising Time (sec)

Column	Main Effect	Total Effect
Water Temp (deg C)	0.121	0.406
Meat (g)	0.079	0.354
Vegi Cabbage	0.103	0.306
Meat Type	0.114	0.263
Batch Size (Count)	0.034	0.151
Dumpling Weight (g)	0.065	0.075

Throughput (Total Weight/Cooking Time)

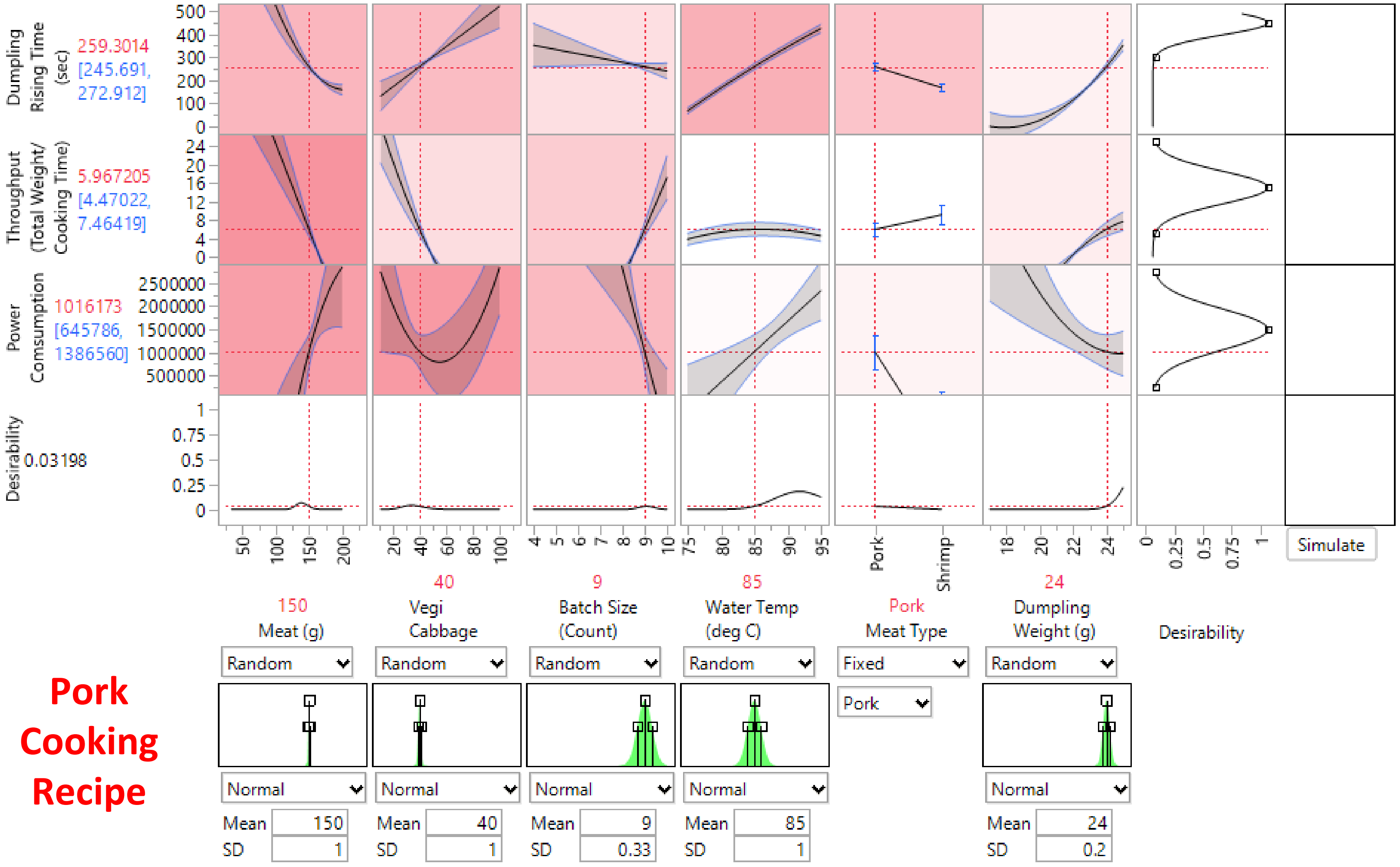
Column	Main Effect	Total Effect
Meat (g)	0.48	0.503
Batch Size (Count)	0.241	0.257
Vegi Cabbage	0.151	0.167
Dumpling Weight (g)	0.061	0.084
Meat Type	0.001	0.002
Water Temp (deg C)	0.001	0.001

Power Comsumption

Column	Main Effect	Total Effect
Vegi Cabbage	0.081	0.54
Meat (g)	0.042	0.531
Batch Size (Count)	0.275	0.304
Meat Type	0.031	0.071
Water Temp (deg C)	0.011	0.033
Dumpling Weight (g)	0.014	0.028

How to Optimize Cooking Process:

Faster Time, Less Duration Variance, **Maximize Throughput and Power Savings** through Monte Carlo Simulation



Pork Cooking Recipe

Artificial Intelligence: Neural Modeling

- The previous Stepwise Regression Modeling approach could not predict Throughput and Power Consumption well.
- We can utilize AI Neural Algorithm to facilitate prediction.
- This model ignores physics. Good thing or bad thing?

Diff between R-Squared may suggest an *Overfit problem!*

Model NTanH(2)

Training

Dumpling Rising Time (sec)

Measures	Value
RSquare	0.3672192
RMSE	93.497643
Mean Abs Dev	60.629446
-LogLikelihood	71.482497
SSE	104901.71
Sum Freq	12

Throughput (Total Weight/Cooking Time)

Measures	Value
RSquare	0.2523678
RMSE	0.4370311
Mean Abs Dev	0.3274427
-LogLikelihood	7.0942505
SSE	2.2919539
Sum Freq	12

Power Comsumption

Measures	Value
RSquare	0.315295
RMSE	504919.09
Mean Abs Dev	368566.65
-LogLikelihood	174.6131
SSE	3.059e+12
Sum Freq	12

Validation

Dumpling Rising Time (sec)

Measures	Value
RSquare	0.3508172
RMSE	40.74726
Mean Abs Dev	35.949221
-LogLikelihood	30.757963
SSE	9962.0353
Sum Freq	6

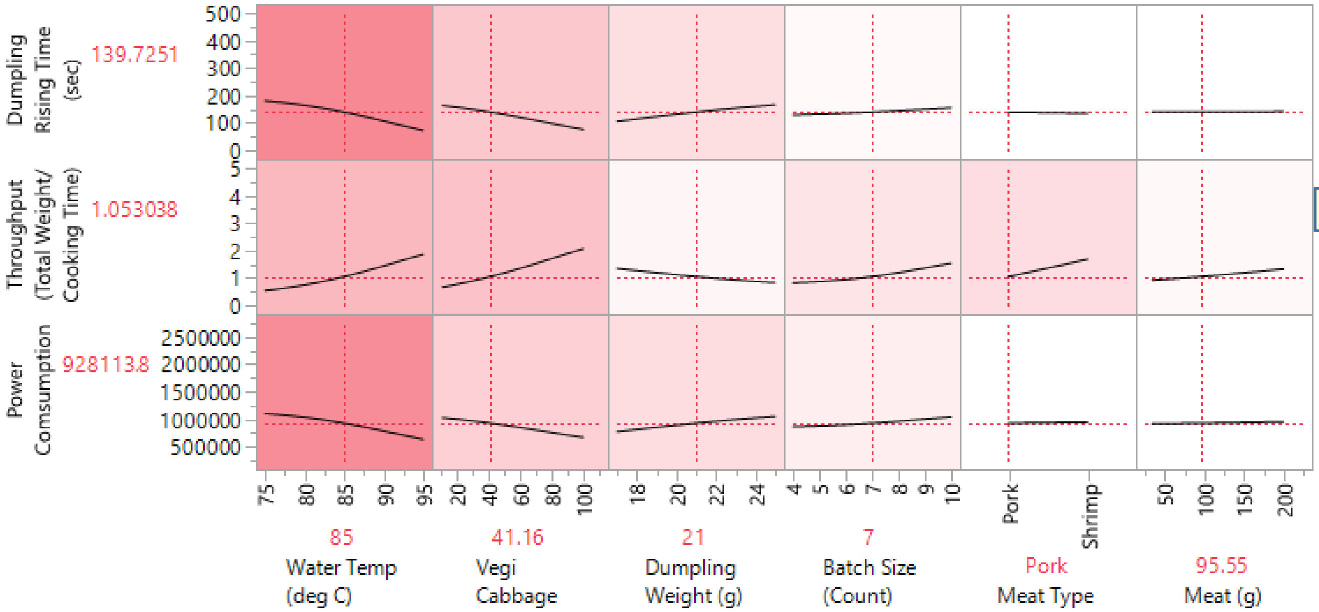
Throughput (Total Weight/Cooking Time)

Measures	Value
RSquare	0.6201162
RMSE	0.7400616
Mean Abs Dev	0.5838333
-LogLikelihood	6.7075004
SSE	3.2861474
Sum Freq	6

Power Comsumption

Measures	Value
RSquare	0.1881791
RMSE	306566.13
Mean Abs Dev	266780.12
-LogLikelihood	84.312764
SSE	5.639e+11
Sum Freq	6

	Generalized RSquare	-LogLikelihood
Training	0.6761	253.18985
Validation	0.7998	121.77823



Artificial Intelligence: Recursive Partitioning

The previous Stepwise Regression Modeling could not predict the Throughput and Power Consumption well. Here we utilize AI Recursive Partitioning Algorithm. The R-squared may be lower for this model compared to the others due to limited sample size, but the model is still good with R-squared at least 50% across all three Y-axes. This is also where we determined our 85 C threshold.

Faster Rising Time

RSquare	RASE	N	Number of Splits	AICc
0.726	53.188693	18	4	213.777

Water Temp (deg C)>=85

		LogWorth	Difference
Count	11	0.9985476	50.5714
Mean	92.818182		
Std Dev	48.799218		

Water Temp (deg C)<85

		LogWorth	Difference
Count	7	1.4889354	196.5
Mean	212.71429		
Std Dev	129.45748		

Maximum Throughput

RSquare	RASE	N	Number of Splits	AICc
0.595	0.5760438	18	4	50.8616

Water Temp (deg C)<95

		LogWorth	Difference
Count	11	1.1550878	0.52791
Mean	0.9876265		
Std Dev	0.4717115		

Water Temp (deg C)>=95

		LogWorth	Difference
Count	7	0.6328377	1.30018
Mean	2.0450419		
Std Dev	1.1354728		

Power Saving

RSquare	RASE	N	Number of Splits	AICc
0.497	379924.59	18	4	533.236

Dumpling Weight (g)<21

		LogWorth	Difference
Count	7	1.3052069	264794
Mean	620110.71		
Std Dev	185661.66		

Dumpling Weight (g)>=21

		LogWorth	Difference
Count	11	0.8329203	657768
Mean	1122670.5		
Std Dev	622615.49		

Summary/Conclusions

- Performed a Dumpling cooking experiment by designing a study using as an 18-run Definitive Screening Design (DSD).
  - Performed model diagnostics to ensure adequate prospective, orthogonality, uniformity and Power.
- Executed experiment systematically.
- Inferred on the cooking time response using the DSD structure modeled with a Stepwise Regression approach using more than one convergence criterion.
- Determined A.I. will not win with such a small sample set, but given a significantly larger data set, may provide “hidden” insights.
- Optimized dumpling cooking experiment.
  - Identified/ quantified Throughput & Power Savings as key metrics.
  - Used Robust Design Monte Carlo Simulation by incorporating all HACCP control points including measurement capability (precision) as inputs.
  - Used Neural Modeling and Recursive Partitioning to go deeper in quantifying our understanding of the physics.

References

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- Boiling, steaming or rinsing?(physics of the Chinese cuisine), Andrey Varlamov, Zheng Zhou, Yan Chen, Fudan University, Shanghai, China, 2018
- Introduction to HACCP: https://www.slideshare.net/Adrienna/introduction-to-haccp-57715003
- HACCP Description Chart: https://www.researchgate.net/figure/HACCP-DESCRIPTION-CHART_tbl5_260401936