SNAME MARITIME 2022 CONVENTION

26-29 September | Houston, TX

Design Activity Modeling

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NAVSEA NAVAL SEA SYSTEMS COMMAND

GUIDED MISSILE DESTROYER DDG(X) PMS 460

CARDINAL engineering

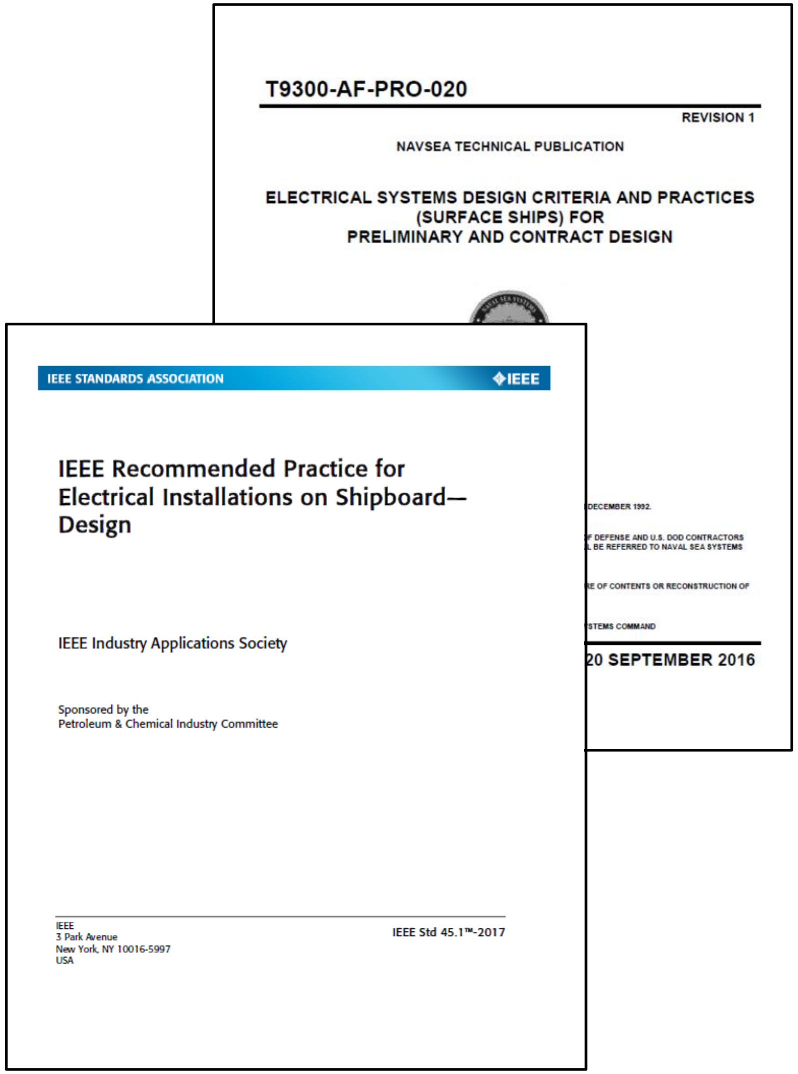
GIBBS & COX A Leidos Company

Agenda

1) What is a Design Activity Model and why do we need it?
2) How does the model work?
3) Example calculation and model capabilities
4) Demonstration

Problem Statement

- **Design requirements exist for the electrical and propulsion systems on a ship.**
  - IEEE 45 series
  - T9300-AF-PRO-020
- **Little to no guidance exists for how to organize or conduct Preliminary and Contract Design.**
  - What activities should be included?
  - What order?
  - How should iteration be addressed?
  - How much should be budgeted?
  - How should a resource loaded schedule be developed?
- **Effort began in 2020 to model the design process.**
  - Build off previous efforts from ~10-15 years ago.



T9300-AF-PRO-020

REVISION 1

NAVSEA TECHNICAL PUBLICATION

ELECTRICAL SYSTEMS DESIGN CRITERIA AND PRACTICES (SURFACE SHIPS) FOR PRELIMINARY AND CONTRACT DESIGN

20 SEPTEMBER 2016

IEEE STANDARDS ASSOCIATION IEEE

IEEE Recommended Practice for Electrical Installations on Shipboard—Design

IEEE Industry Applications Society

Sponsored by the
Petroleum & Chemical Industry Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

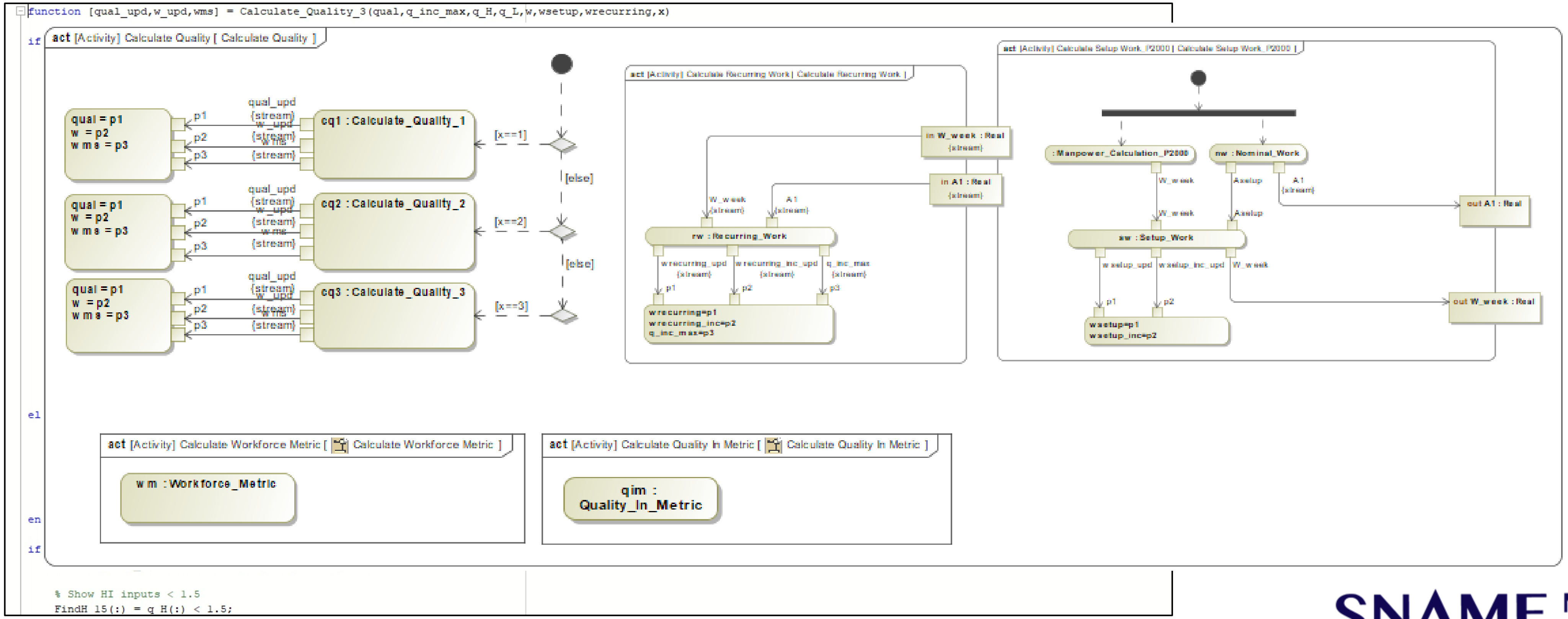
IEEE Std 45.1™-2017

Why Model?

- To determine the required budget and duration of the preliminary and contract.
- To assist in developing Tasking Documents (standard statements of work) for Design Activities.
- To assist in the management of the design process as it executes.
- To promote continuous process improvement in the design process.

Design Activity Model (DAM)

- **A schedule optimization tool that utilizes the capability of MagicDraw to integrate with MATLAB for parametric simulations**
  - Allows for logically complex algorithms to be compressed down to manageable “actions” in MagicDraw



Defining Important Terms

- **Activity Models**
  - The digital counterpart of a real design activity that produces a "degree of completion" to represent a physical output through the use of various algorithms
  - Maps physical inputs to appropriately valued parameters

Design Activities Simulated in the Model

- Develop Power System Architectures
- Electric Power Load Analysis (EPLA)
- Load List
- Primary Power System Design
- Zonal Power System Design
- Propulsion System Design
- Casualty Power System Design
- ES Concept of Operations
- Electric Plant and Propulsion Controls
- Endurance and Annual Fuel
- Dynamic Simulation
- Reliability Analysis
- Quality of Service Analysis
- Vulnerability and Recoverability Analysis
- Arc Flash Analysis
- System Safety Analysis and Hazard Analysis
- Cybersecurity Analysis
- Product Support Analysis
- Human Engineering Analysis
- Develop Specifications
- Develop strategy for power system flexibility
- Assess Power System flexibility
- Electrical System and Propulsion System Development Testing
- Develop mission System - Power System Interface
- Cost Engineering Analysis
- Develop Configurations
- Set Reduction

Defining Important Terms

- **Activity Model**
  - The digital counterpart of a real-life design activity that produces a degree of completion instead of a tangible output through the use of various algorithms
  - Maps physical inputs to appropriately valued parameters
- **Product**
  - The output of an activity model
  - Some activities have several products (EPLA)
- **Quality**
  - The degree of completion of the product of a given activity
  - Represented as an interval from 0.0 – 5.0
  - Product quality
  - Requirement quality
  - Interdependent products

Design Structure Matrix

Product Providing the Input

Product Receiving the Input

		100	200	210	220	230	300	400	500	600	700	800	810	900	1000	1100	1110	1120	1130	1140	1150	1160	1200	1300	1400	1410	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700
100	1																																						
200	2	S					S					W	W																									S	
210	3	S					S					W	W																									S	
220	4	S					S					W	W																									S	
230	5	S					S					W	W																									S	
300	6	S																																				W	
400	7	S	W								W	W	W	W	W	W	W	W	W	W	W	W	W	W	W		W	W	W	W	W		W	W	W		W	W	
500	8	S	W				W				W	W		W		W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W		W	W	W		W	W	
600	9	S						W					S		W			S	S		S	S	W	W				W	W	W	W				S		W		
700	10		S				S	S	S																W	W												S	
800	11	S						S	S	S				S				W																				S	
810	12	S						S		S				S				W																				S	
900	13	S					S	S	S	S	W	S	S			S	S	S	S	S	S	S		S	W	W			S		W		S	W	W	S	W	S	
1000	14		S					S	W	S		S	S																									S	
1100	15		S				S	S	S	S		S	S	S																					W			S	
1110	16		S				S	S	S	S		S	S	S																					W			S	
1120	17		S				S	S	S	S		S	S	S																					W			S	
1130	18		S				S	S	S	S		S	S	S																					W			S	
1140	19		S				S	S	S	S		S	S	S																					W			S	
1150	20		S				S	S	S	S		S	S	S																					W			S	
1160	21		S				S	S	S	S		S	S	S																					W			S	
1200	22							S	S	S	W	S	S	S																								S	
1300	23		S	S	S	S	S	S	S			S				W	W				W		S															S	
1400	24		S				S	S	S	S	S	S	S	W																								S	
1410	25		S				S	S	S	S	S	S	S	W																								S	
1500	26							S	S	S		S	S																									S	
1600	27							S	S	S	W	S	S	S																								S	
1700	28							S	S	S	W	S	S	S																								S	
1800	29							S	S	S	W	S	S	S									S								S							S	
1900	30	W						S	S	S	W	S	S	S										S	W	W		S		W			W			W		S	
2000	31	W	S	S	S	S	W	S	S	S	S	S	S	S	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W		W	W	W	S	W	S	S
2100	32	S																																					
2200	33	S	S					S	S	S				S																			S					S	
2300	34							S	S	S	W			S		W	W	W	W	W	W	W																S	
2400	35	W					W	W	W			W		W																									
2500	36							S	S	S	W			S									S							S								S	
2600	37	S	S				W	S	S	S	W			W																									S
2700	38		S	S	S	S										S	S	S	S	S	S	S	S	S	S	S	S	S	S	W	W			W	S		S	S	

Design Structure Matrix

Product Receiving the Input		Requirement Providing the Input																								
		R-010	R-020	R-030	R-040	R-050	R-060	R-070	R-080	R-090	R-100	R-110	R-120	R-130	R-140	R-150	R-160	R-170	R-180	R-190	R-200	R-210	R-220	R-230	R-240	R-250
100	1																				S	S				
200	2		S	S	W			S																		
210	3		S	S	W			S																		
220	4		S	S	W			S																		
230	5		S	S	W			S																		
300	6		S			S	S	S	S	S											S					
400	7			W		W	W																			
500	8			W		W	W																			
600	9			S		S					S															
700	10											S														
800	11										S	W														
810	12										S	W														
900	13																									
1000	14			S							S			S	S											
1100	15		S								S												S	S		
1110	16		S								S												S	S		
1120	17		S								S												S	S		
1130	18		S								S												S	S		
1140	19		S								S												S	S		
1150	20		S								S												S	S		
1160	21		S								S												S	S		
1200	22																								S	S
1300	23												S													
1400	24											S														
1410	25											S														
1500	26					S																				
1600	27					S										S										
1700	28																S									
1800	29																	S								
1900	30																									
2000	31	S	S	S	W	S	W	S	W	W	W	S	S	W	W	W	W	W	S	W	W	W	W	W	W	W
2100	32			S															S							
2200	33			S																						
2300	34																									
2400	35																									
2500	36					W	W													S						
2600	37					S	W													W						
2700	38																									

Outputs and Insights From the DAM

- **Estimate of duration and cost of conducting Preliminary and Contract Design**
  - Ship power and propulsion design only
- **Demonstrates Design Activity Interdependence**
- **Rate of Convergence of Iterative Design Process**
- **Improved understanding of design**
  - Enables the user to model different design processes implementing different design methods to understand schedule and cost trade-offs.
  - Enable continuous process improvement.

What the DAM Does Not Capture

- **Does not model (need to budget for these items separately)**
  - Financial Management
  - Risk Management
  - Program Management
  - Contracting
  - Technical, Programmatic, and Financial Reviews
  - Establishment of Test Facilities and procurement of Test articles and test equipment
  - Procurement of hardware or software for conducting simulations or other analysis

Important Parameters of Activity Models

- **Number of Engineers Assigned to an Activity**
  - Senior or junior engineers
  - $n_{FTE} = n_{senior} + n_{junior}$
- **Effective Workforce and Efficiency of Junior Engineers**
  - $L_1 = n_{senior} + L_{factor} n_{junior}$
- **Effective Work Accomplished by a Team**

For $n_{FTE} > 1$ $\quad f_{FTE}(n_{FTE}) = \frac{B_0}{n_{FTE}} + B_1 + B_2 n_{FTE} + B_3 n_{FTE}^2$

For $n_{FTE} \leq 1$ $\quad f_{FTE}(n_{FTE}) = 1.0$

$B_0 = 0.3631$
$B_1 = 0.6369$
$B_2 = 0.0$
$B_3 = 0.0$

Mao A, Mason W, Suri S, Watts DJ (2016) “An Experimental Study of Team Size and Performance on a Complex Task. PLoS ONE 11(4): e0153048. doi:10.1371/journal.pone.0153048

Important Parameters of Activity Models

- **Setup Work**
  - Represents the "initial work" necessary in any design activity
  - Necessary to complete before an activity can begin quality convergence
  - An interval from 0.0 – 1.0 and must be 1.0 to produce quality
- **Recurring Work**
  - Represents the "actual work" performed in any design activity
  - An interval from 0.0 – 1.0 but does not have to be 1.0
  - The greater recurring work is, the greater the minimum quality output will be

Important Parameters of Activity Models

- **Level of Precision**
  - Low, Moderate, High ($x = [1,2,3]$)
  - Can represent different things based on the activity model (phases of execution, precision of tools, depth of analyses, etc.)
- **Adjustment Factors**
  - An array whose elements range from 0.0 – 2.0
  - Represent factors such as personnel experience, level of tool support, documentation, etc

Example of Adjustment Factors

Architecture Requirements Volatility	F_{setup_k}	F_k
Much Less than Normal	0.8	0.8
Less Than Normal	0.9	0.9
Normal	1	1
More than Normal	1.1	1.1
Much more than normal	1.25	1.25
Personnel experience		
Very Inexperienced	2	2
Inexperienced	1.5	1.5
Normal	1	1
Experienced	0.7	0.7
Very Experienced	0.5	0.5
Tool Support		
Stand-alone tools, little data	5	5
Stand-alone tools, moderate missing data	2	2
Normal – stand alone, some missing data	1	1
Integrated with IDE, some missing data	0.7	0.7
Integrated with IDE – no missing data	0.5	0.5

Process Capability	F_{setup_k}	F_k
Much Less than Normal	1	1
Less Than Normal	1	1
Normal	1	1
More than Normal	1	1
Much more than normal	1	1
Documentation		
Much less than normal	0.5	0.5
Less than normal	0.75	0.75
Normal	1	1
More than normal	1.5	1.5
Much more than normal	2	2

Design Activities in the Model

Model Description Documents (MDDs)

- Model Description Documents provide understanding of inter-relationships between design activities.

    1. Introduction / Purpose
        - Describes the activity purpose and identifies outputs
    2. Inputs
        - Lists necessary inputs to the given activity that are the output qualities of other activities or just requirement qualities
    3. Outputs
        - Lists the output(s) of the activity and what each output would translate to in a physical output

Model Description Documents (MDDs)

4. Controls
   - Size function default value(s) (f_size)
   - Default workforce numbers (n_{senior}, n_{junior})
   - Default junior engineer efficiency (L_{factor})
   - What the LoP represents (x)
5. Mechanisms
   - Effort (what the setup/recurring work translate to)
   - Nominal workloads based on the LoP (A_{setup}, A_1)
   - Adjustment factor tables (F_{setup}, F_1)
   - Labor Categories

Example Calculation

Calculate Setup Workload:

$$W_{setup} = A_{setup} \prod_{k=0}^{K-1} F_{setup}$$

Inspired by the COSYSMO Estimation Equation

Calculate Recurring Workload:

$$W_{recurring} = A_1\, f_{size}(N_0) \prod_{k=0}^{K-1} F_k$$

Calculate work for the week:

$$n_{FTE} = senior + junior$$

$$n_{FTE} \leq 1:\ f_{FTE}(n_{FTE})$$

$$L_1 = senior + efficiency(junior)$$

$$W_{week} = L_1 f_{FTE} t_f$$

Calculate the *increase* in setup work per model iteration (work week):

$$w_{setup\_inc} = \frac{W_{week}}{W_{setup}}$$

If the increase in setup work is greater than or equal 1.0, then setup work is finished:

$$w_{setup} = 1.0$$

If the increase in setup work is less than 1.0 , the effort will continue in week 2 and beyond until:

$$w_{setup} + w_{setup\_inc} \geq 1$$

Recalculate remaining effective work accomplished after finishing setup work

$$W_{week} = (W_{setup})(w_{setup}) + w_{setup\_inc} - 1)$$

Use the remaining effective work accomplished for the week and apply it to recurring work:

$$w_{recurring\_inc} = \frac{\mathrm{W_{week}}}{W_{recurring}}$$

Calculate recurring work:

$$w_{recurring} = \min(w_{recurring} + w_{recurring\_inc}, 1)$$

Calculate also the maximum allowable increase in quality:

$$q_{inc\_max} = 0.5\left(w_{recurring\_inc}\right)$$

As an example of the calculation of quality, the design activity "Develop Power System Architecture" receives two high-quality inputs (R200, R210):

If one of the high-quality inputs is of a quality less than 4.0:

$$R200 = 3.0$$
$$R210 = 5.0$$
$$q_0 = 3.5 + 0.5w_{recurring} + \frac{1.0}{4.0}\left(\frac{1}{N+M}\right)\sum_{n=1}^{N} \min\left(q_{hi\_n}, 4.0\right)$$

If all high-quality inputs are of a quality greater than 4.0:

$$R200 = 4.5$$
$$R210 = 4.5$$
$$q_0 = 4.5 + 0.5w_{recurring}$$

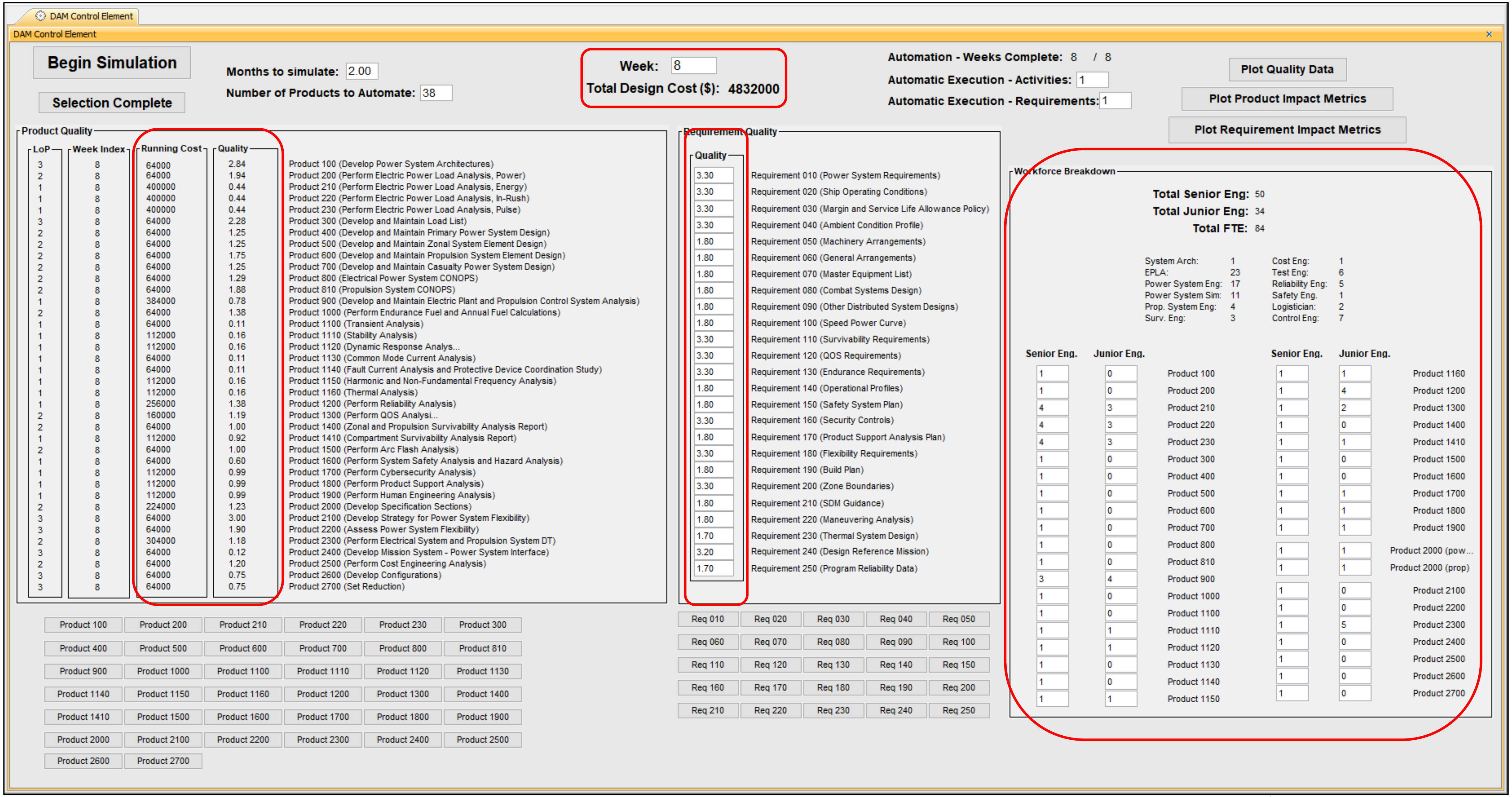
A low level of precision ($x = 1$) may have a better rate of quality increase, but the quality of a design activity is capped at 1.5

Likewise, a medium level of precision ($x = 2$) may cause quality to converge slight slower, but is capped at 3.5

Finally, the highest level of precision ($x = 3$) may have slowest rate of convergence, but allows the design activity to achieve completion ($quality = 5.0$)

Additionally, the level of precision effects how quality is calculated and effects the possible outputs as well.

However, we must take into consideration the maximum allowable increase in quality. If the maximum allowable increase in quality is less than any calculated quality, it must be this output by default.


DAM Control Element
DAM Control Element
Begin Simulation
Selection Complete
Months to simulate: 2.00
Number of Products to Automate: 38
Week: 8
Total Design Cost ($): 4832000
Automation - Weeks Complete: 8 / 8
Automatic Execution - Activities: 1
Automatic Execution - Requirements: 1
Plot Quality Data
Plot Product Impact Metrics
Plot Requirement Impact Metrics
Product Quality
LoP Week Index Running Cost Quality
3 8 64000 2.84 Product 100 (Develop Power System Architectures)
2 8 64000 1.94 Product 200 (Perform Electric Power Load Analysis, Power)
1 8 400000 0.44 Product 210 (Perform Electric Power Load Analysis, Energy)
1 8 400000 0.44 Product 220 (Perform Electric Power Load Analysis, In-Rush)
1 8 400000 0.44 Product 230 (Perform Electric Power Load Analysis, Pulse)
3 8 64000 2.28 Product 300 (Develop and Maintain Load List)
2 8 64000 1.25 Product 400 (Develop and Maintain Primary Power System Design)
2 8 64000 1.25 Product 500 (Develop and Maintain Zonal System Element Design)
2 8 64000 1.75 Product 600 (Develop and Maintain Propulsion System Element Design)
2 8 64000 1.25 Product 700 (Develop and Maintain Casualty Power System Design)
2 8 64000 1.29 Product 800 (Electrical Power System CONOPS)
2 8 64000 1.88 Product 810 (Propulsion System CONOPS)
1 8 384000 0.78 Product 900 (Develop and Maintain Electric Plant and Propulsion Control System Analysis)
2 8 64000 1.38 Product 1000 (Perform Endurance Fuel and Annual Fuel Calculations)
1 8 64000 0.11 Product 1100 (Transient Analysis)
1 8 112000 0.16 Product 1110 (Stability Analysis)
1 8 112000 0.16 Product 1120 (Dynamic Response Analys...
1 8 64000 0.11 Product 1130 (Common Mode Current Analysis)
1 8 64000 0.11 Product 1140 (Fault Current Analysis and Protective Device Coordination Study)
1 8 112000 0.16 Product 1150 (Harmonic and Non-Fundamental Frequency Analysis)
1 8 112000 0.16 Product 1160 (Thermal Analysis)
1 8 256000 1.38 Product 1200 (Perform Reliability Analysis)
2 8 160000 1.19 Product 1300 (Perform QOS Analysi...
2 8 64000 1.00 Product 1400 (Zonal and Propulsion Survivability Analysis Report)
1 8 112000 0.92 Product 1410 (Compartment Survivability Analysis Report)
2 8 64000 1.00 Product 1500 (Perform Arc Flash Analysis)
1 8 64000 0.60 Product 1600 (Perform System Safety Analysis and Hazard Analysis)
1 8 112000 0.99 Product 1700 (Perform Cybersecurity Analysis)
1 8 112000 0.99 Product 1800 (Perform Product Support Analysis)
1 8 112000 0.99 Product 1900 (Perform Human Engineering Analysis)
2 8 224000 1.23 Product 2000 (Develop Specification Sections)
3 8 64000 3.00 Product 2100 (Develop Strategy for Power System Flexibility)
3 8 64000 1.90 Product 2200 (Assess Power System Flexibility)
2 8 304000 1.18 Product 2300 (Perform Electrical System and Propulsion System DT)
3 8 64000 0.12 Product 2400 (Develop Mission System - Power System Interface)
2 8 64000 1.20 Product 2500 (Perform Cost Engineering Analysis)
3 8 64000 0.75 Product 2600 (Develop Configurations)
3 8 64000 0.75 Product 2700 (Set Reduction)
Product 100 Product 200 Product 210 Product 220 Product 230 Product 300
Product 400 Product 500 Product 600 Product 700 Product 800 Product 810
Product 900 Product 1000 Product 1100 Product 1110 Product 1120 Product 1130
Product 1140 Product 1150 Product 1160 Product 1200 Product 1300 Product 1400
Product 1410 Product 1500 Product 1600 Product 1700 Product 1800 Product 1900
Product 2000 Product 2100 Product 2200 Product 2300 Product 2400 Product 2500
Product 2600 Product 2700
Requirement Quality
Quality
3.30 Requirement 010 (Power System Requirements)
3.30 Requirement 020 (Ship Operating Conditions)
3.30 Requirement 030 (Margin and Service Life Allowance Policy)
3.30 Requirement 040 (Ambient Condition Profile)
1.80 Requirement 050 (Machinery Arrangements)
1.80 Requirement 060 (General Arrangements)
1.80 Requirement 070 (Master Equipment List)
1.80 Requirement 080 (Combat Systems Design)
1.80 Requirement 090 (Other Distributed System Designs)
1.80 Requirement 100 (Speed Power Curve)
3.30 Requirement 110 (Survivability Requirements)
3.30 Requirement 120 (QOS Requirements)
3.30 Requirement 130 (Endurance Requirements)
1.80 Requirement 140 (Operational Profiles)
1.80 Requirement 150 (Safety System Plan)
3.30 Requirement 160 (Security Controls)
1.80 Requirement 170 (Product Support Analysis Plan)
3.30 Requirement 180 (Flexibility Requirements)
1.80 Requirement 190 (Build Plan)
3.30 Requirement 200 (Zone Boundaries)
1.80 Requirement 210 (SDM Guidance)
1.80 Requirement 220 (Maneuvering Analysis)
1.70 Requirement 230 (Thermal System Design)
3.20 Requirement 240 (Design Reference Mission)
1.70 Requirement 250 (Program Reliability Data)
Req 010 Req 020 Req 030 Req 040 Req 050
Req 060 Req 070 Req 080 Req 090 Req 100
Req 110 Req 120 Req 130 Req 140 Req 150
Req 160 Req 170 Req 180 Req 190 Req 200
Req 210 Req 220 Req 230 Req 240 Req 250
Workforce Breakdown
Total Senior Eng: 50
Total Junior Eng: 34
Total FTE: 84
System Arch: 1
EPLA: 23
Power System Eng: 17
Power System Sim: 11
Prop. System Eng: 4
Surv. Eng: 3
Cost Eng: 1
Test Eng: 6
Reliability Eng: 5
Safety Eng. 1
Logistician: 2
Control Eng: 7
Senior Eng. Junior Eng.
1 0 Product 100
1 0 Product 200
4 3 Product 210
4 3 Product 220
4 3 Product 230
1 0 Product 300
1 0 Product 400
1 0 Product 500
1 0 Product 600
1 0 Product 700
1 0 Product 800
1 0 Product 810
3 4 Product 900
1 0 Product 1000
1 0 Product 1100
1 1 Product 1110
1 1 Product 1120
1 0 Product 1130
1 0 Product 1140
1 1 Product 1150
Senior Eng. Junior Eng.
1 1 Product 1160
1 4 Product 1200
1 2 Product 1300
1 0 Product 1400
1 1 Product 1410
1 0 Product 1500
1 0 Product 1600
1 1 Product 1700
1 1 Product 1800
1 1 Product 1900
1 1 Product 2000 (pow...
1 1 Product 2000 (prop)
1 0 Product 2100
1 0 Product 2200
1 5 Product 2300
1 0 Product 2400
1 0 Product 2500
1 0 Product 2600
1 0 Product 2700

Metrics

- **Workforce Metrics – [0, 0, 0]**
  - 0 Not the active precision level
  - 1 Setup limited (active precision level)
  - 2 Recurring limited (active precision level)
  - 3 Quality increment limit (active precision level)
  - 4 Limited by level of precision or input quality
- **Input Quality Metrics – [0, 0, 0]**
  - 0 Output quality not limited by inputs, or not the active precision level
  - 1 Output quality limited by at least one input

Metrics

- **Impact Metrics– [0, 0, 0, … ,0]**

  - An array of 0’s and 1’s that indicates what activities the quality of the product that owns the impact metric affects

  0 Not hindering the production of another product quality
  1 Hindering the production of another product quality

Current Capabilities of the DAM

- **Direct Outputs**
  - Degree of completion of any given design activity model
  - Estimated cost and duration of individual design activities
  - Estimated total cost and duration of the whole design schedule

- **Additional Information**
  - Graphic User Interface (GUI)
  - Various metrics to identify obstacles for convergence
  - MATLAB plots of above metrics and activity output product degree of completion over time

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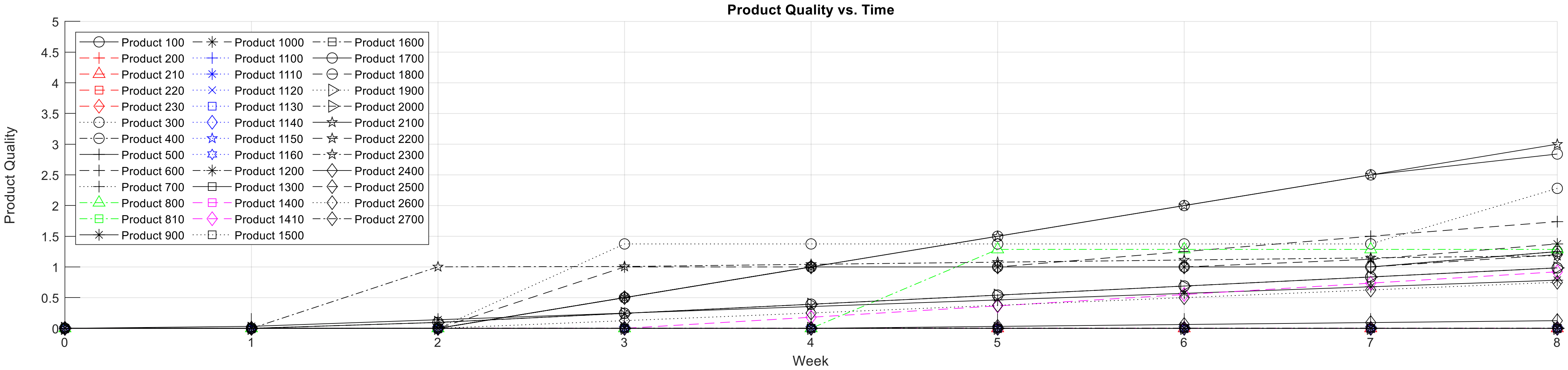

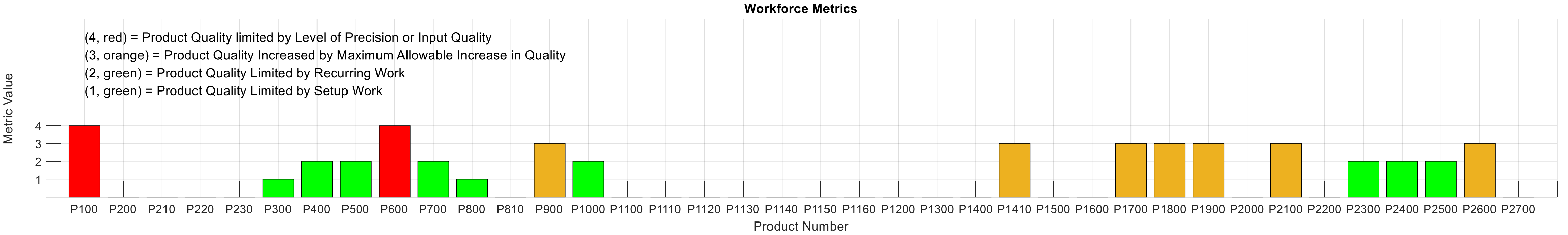

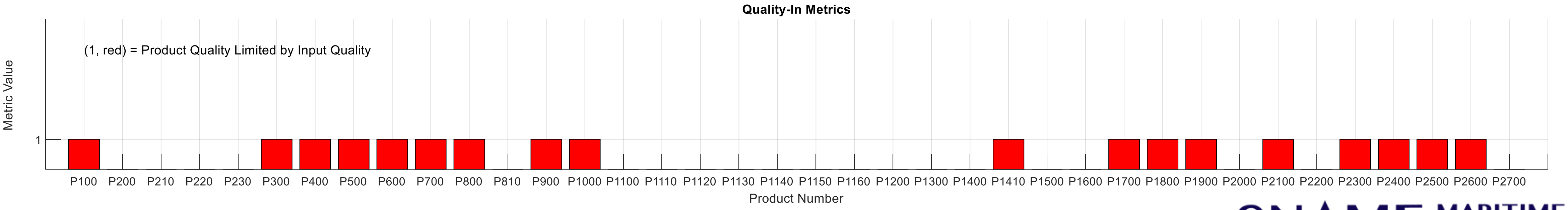

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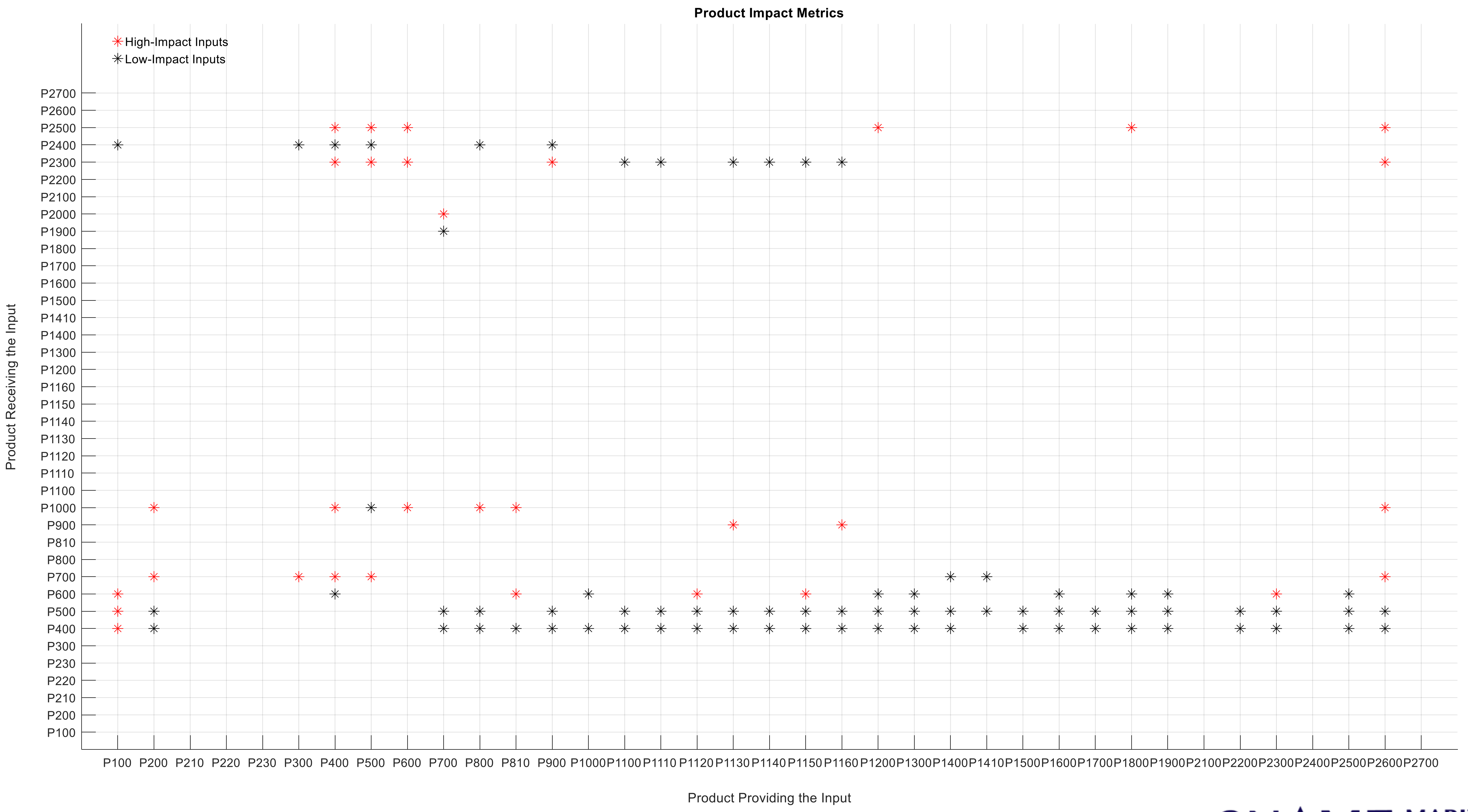

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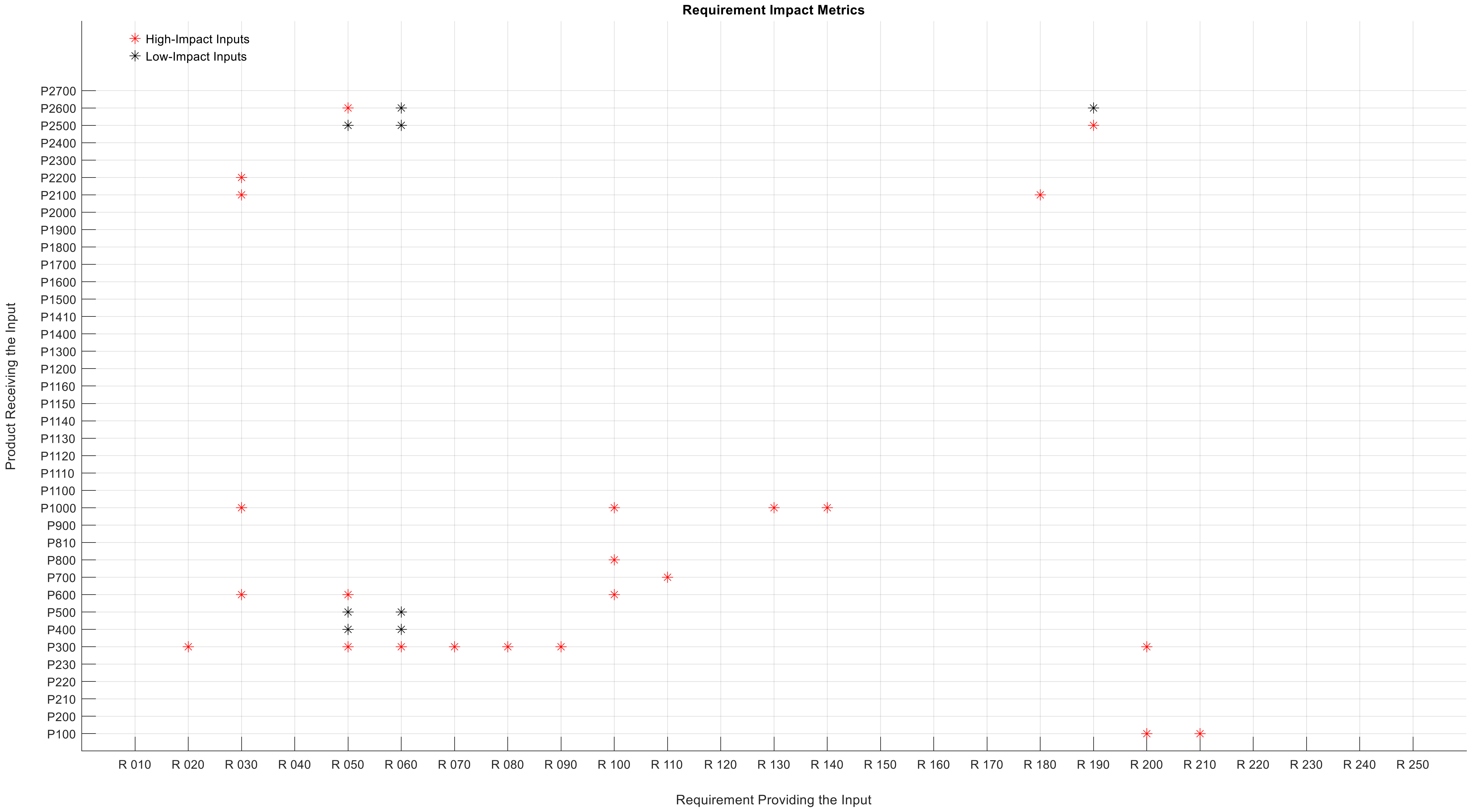
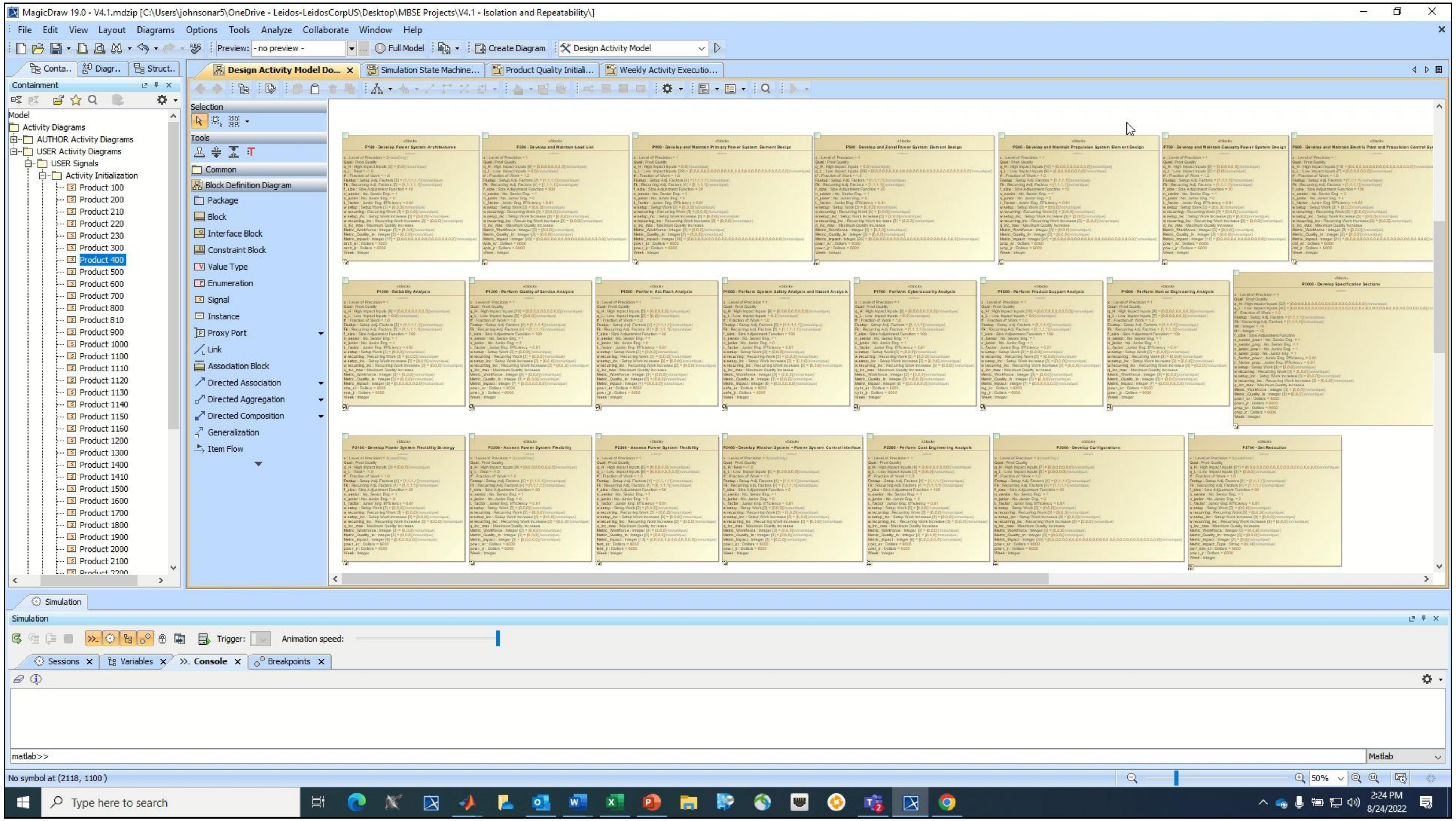
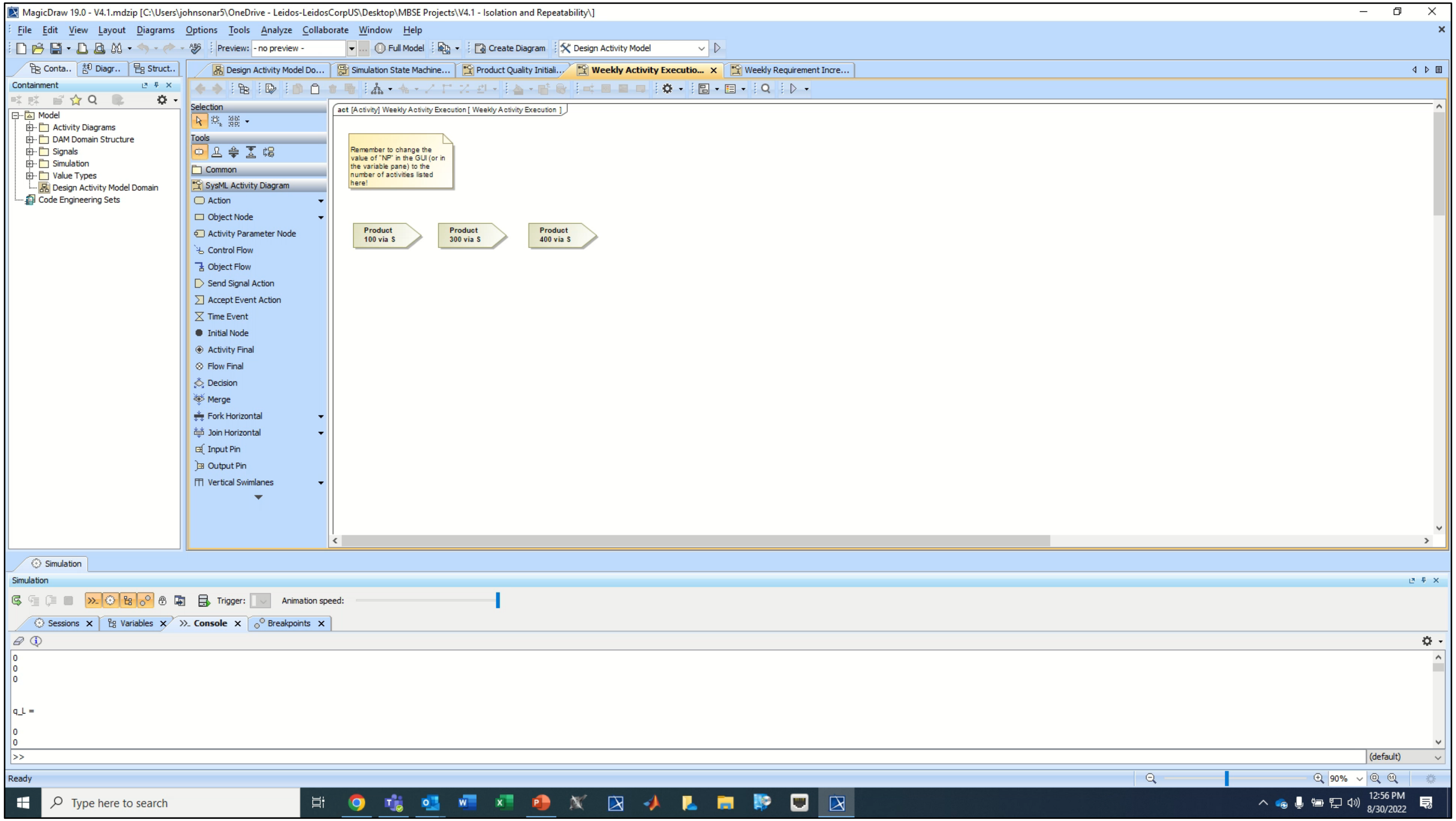

Requirement Impact Metrics
High-Impact Inputs
Low-Impact Inputs
Product Receiving the Input
P2700
P2600
P2500
P2400
P2300
P2200
P2100
P2000
P1900
P1800
P1700
P1600
P1500
P1410
P1400
P1300
P1200
P1160
P1150
P1140
P1130
P1120
P1110
P1100
P1000
P900
P810
P800
P700
P600
P500
P400
P300
P230
P220
P210
P200
P100
R 010
R 020
R 030
R 040
R 050
R 060
R 070
R 080
R 090
R 100
R 110
R 120
R 130
R 140
R 150
R 160
R 170
R 180
R 190
R 200
R 210
R 220
R 230
R 240
R 250
Requirement Providing the Input

Demonstration



Demonstration



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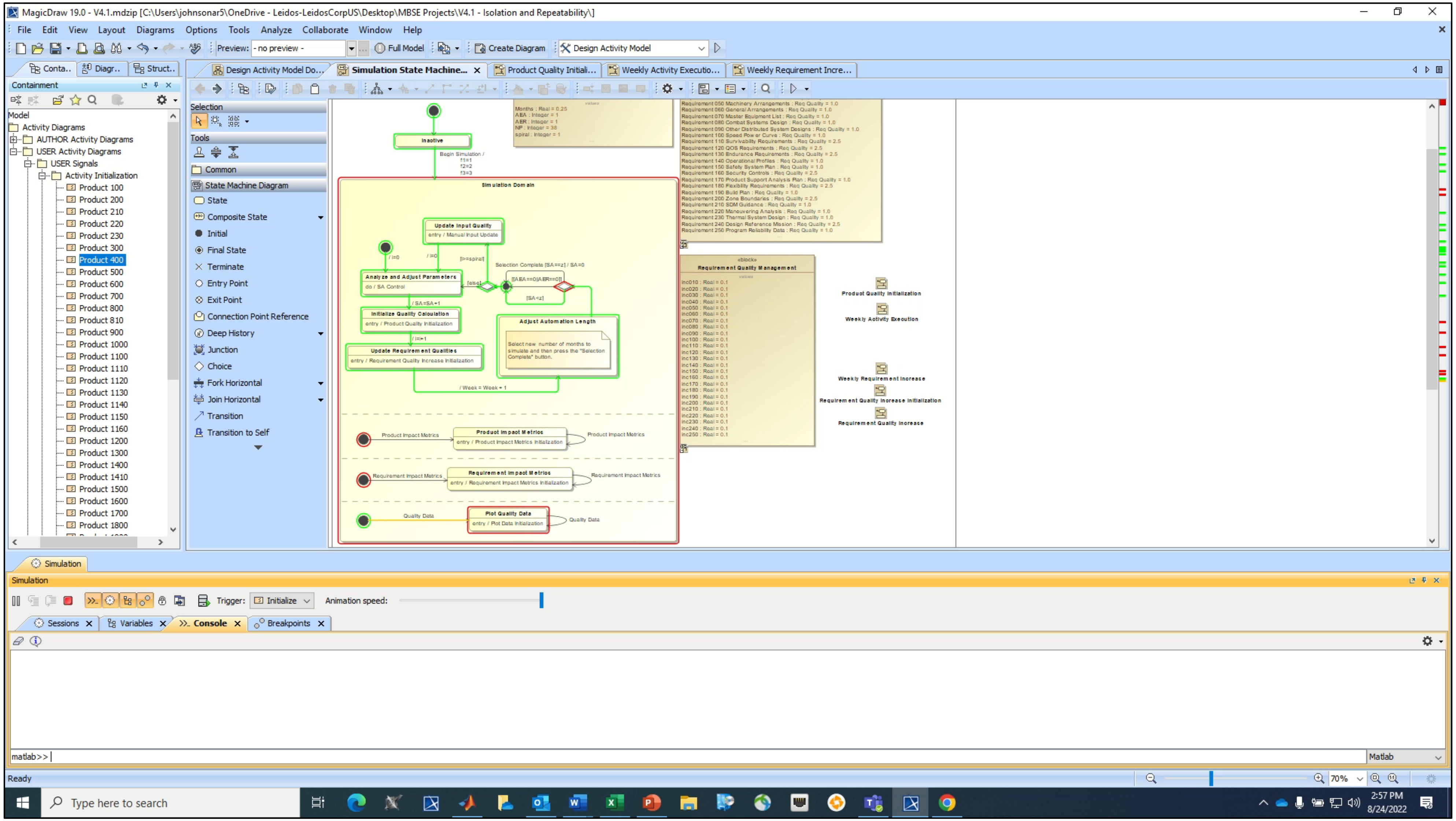
Demonstration



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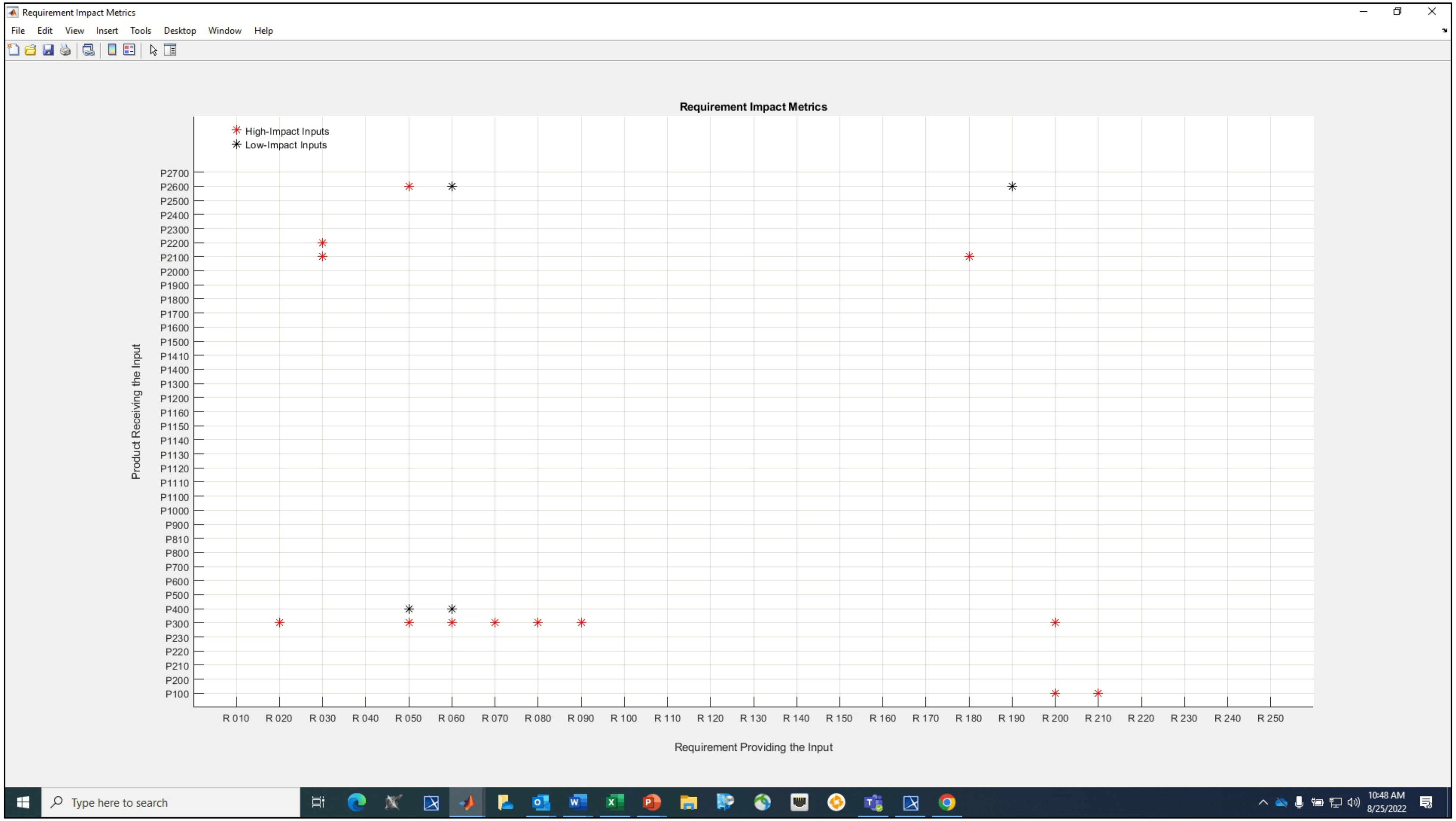
Demonstration



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Thank you for your attention.
This concludes the presentation.

Questions?