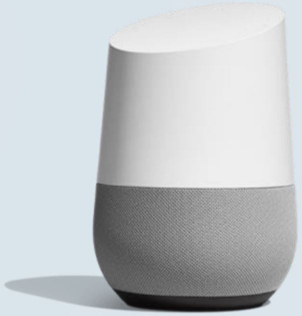
How to determine the success of Smart Products?
A Machine Learning Approach

Louis Püschel

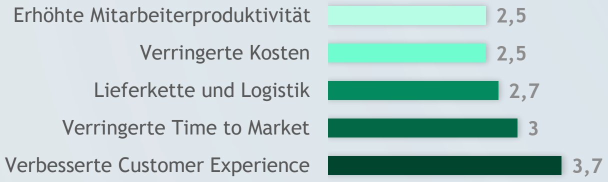
WHAT IS A SMART PRODUCT?



"The Internet of Things (IoT) refers to the connectivity of physical objects, equipped with sensors and actuators, to the Internet via data communication technology, enabling interaction with and/or among these objects."

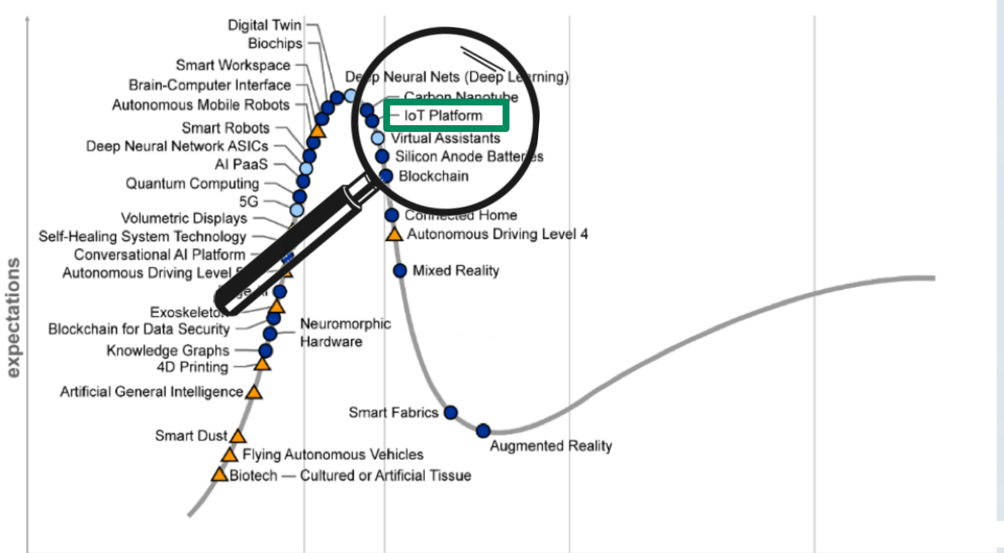
MOTIVATION

Internet der Dinge:
Wertschöpfung bis 2022 $14,4 Billionen



Anzahl verbundener Geräte

2015	2025
ca. 15,4 Milliarden	ca. 75,4 Milliarden



Internet der Dinge im Gartner Hype Cycle 2018

Smart City

Exemplarisch

Husqvarna
Google
BOSCH
amazon.com

Health, Well-Being

Exemplarisch

PHILIPS
CliniCloud
fitbit
GARMIN
SIEMENS
Microsoft

Industrial

Exemplarisch

ROLLS ROYCE
CATERPILLAR
GE
HILTI
BOSCH
AIRBUS

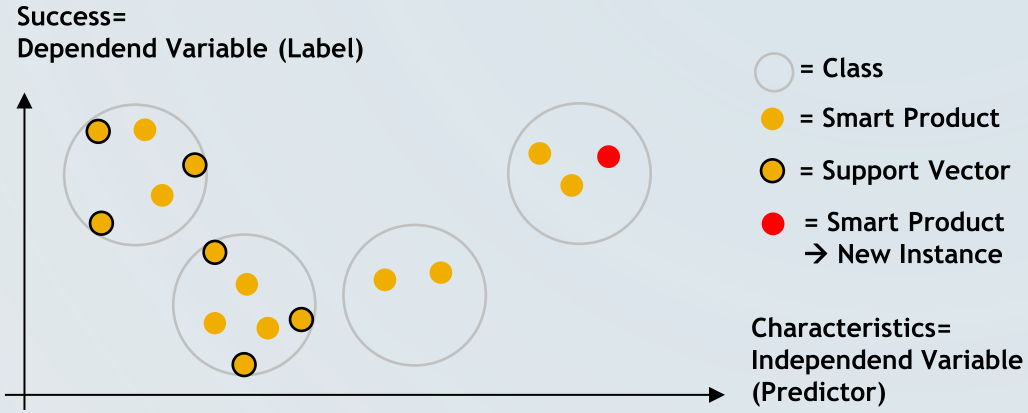
PROJECT QUESTION?

Which Smart Products are especially successfull?

Which kind of Smart Product is my Product?

✓ Prediction with a Machine Learning Approach

PREDICTION BASED ON SUPPORT VECTOR MACHINE



Success=
Dependend Variable (Label)

○ = Class

● = Smart Product

● = Support Vector

● = Smart Product
→ New Instance

Characteristics=
Independend Variable
(Predictor)

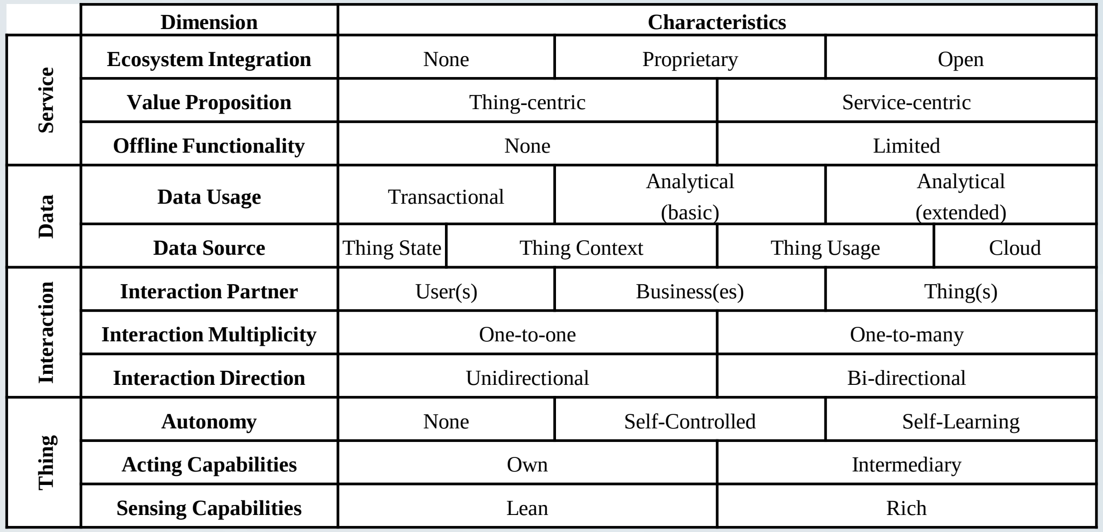
Explanation

- **SVM trains** on the basis of **characteristics** and **market success** of the smart products
- **Depending** on the **characteristics** of the smart product, it will have a **certain success**
- **Success** results from **Google search queries**
- **Apply SVM** to an entirely **new object/instance**

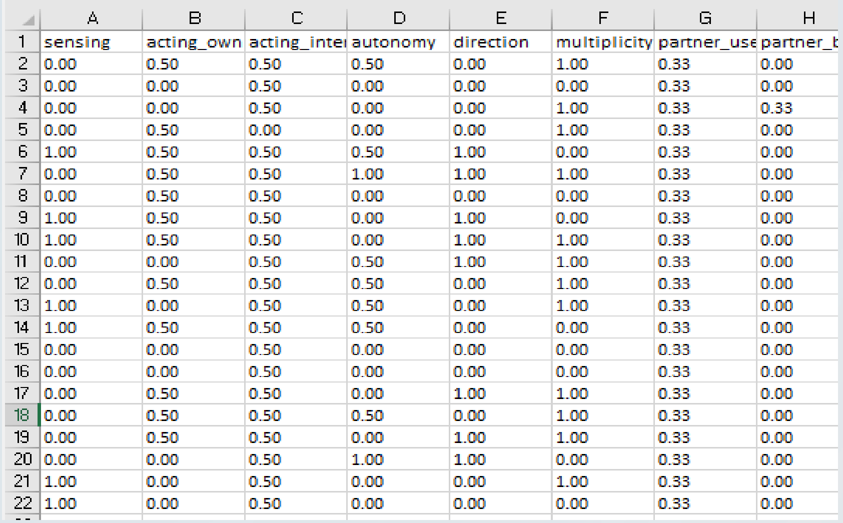
WHAT DO WE NEED? THE PREWORK!

Taxonomy
General description of Smart Products.

Data set
About 200 classified Smart Products, related success and cluster affiliation.

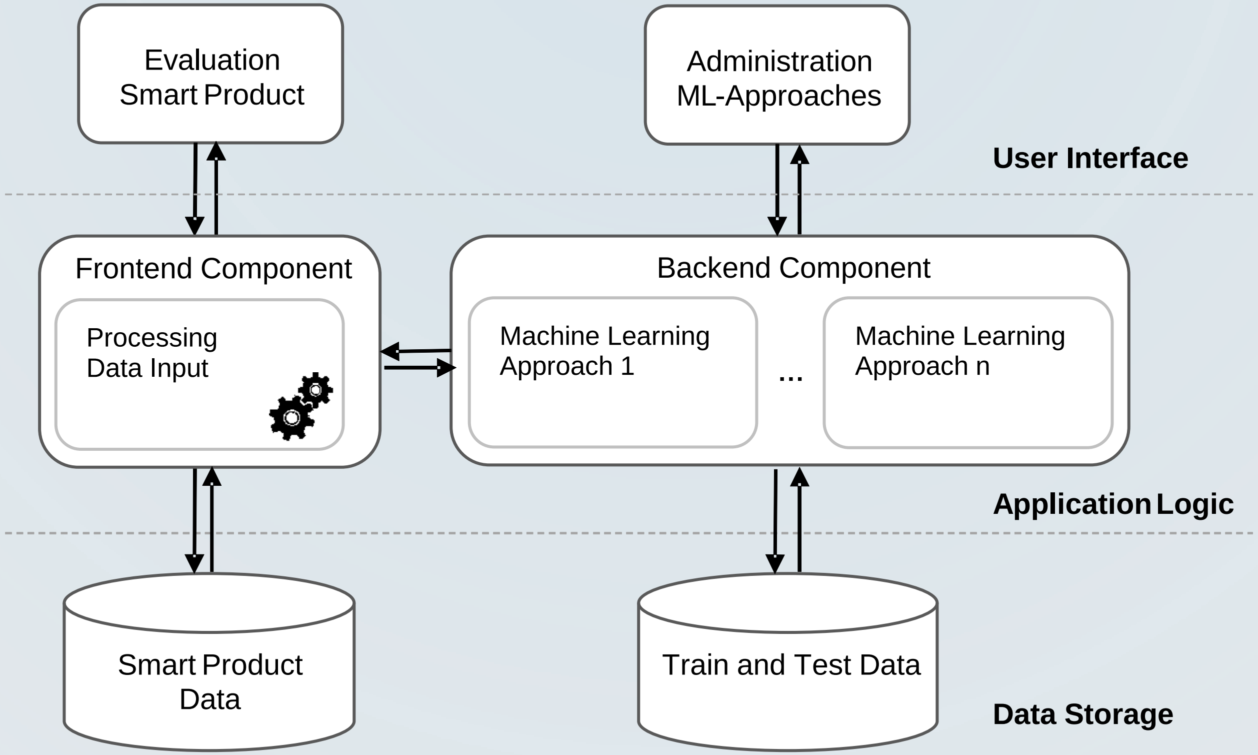


	Dimension	Characteristics			
Service	Ecosystem Integration	None	Proprietary	Open	
	Value Proposition	Thing-centric	Service-centric		
	Offline Functionality	None	Limited		
Data	Data Usage	Transactional	Analytical (basic)	Analytical (extended)	
	Data Source	Thing State	Thing Context	Thing Usage	Cloud
Interaction	Interaction Partner	User(s)	Business(es)	Thing(s)	
	Interaction Multiplicity	One-to-one	One-to-many		
	Interaction Direction	Unidirectional	Bi-directional		
Thing	Autonomy	None	Self-Controlled	Self-Learning	
	Acting Capabilities	Own	Intermediary		
	Sensing Capabilities	Lean	Rich		

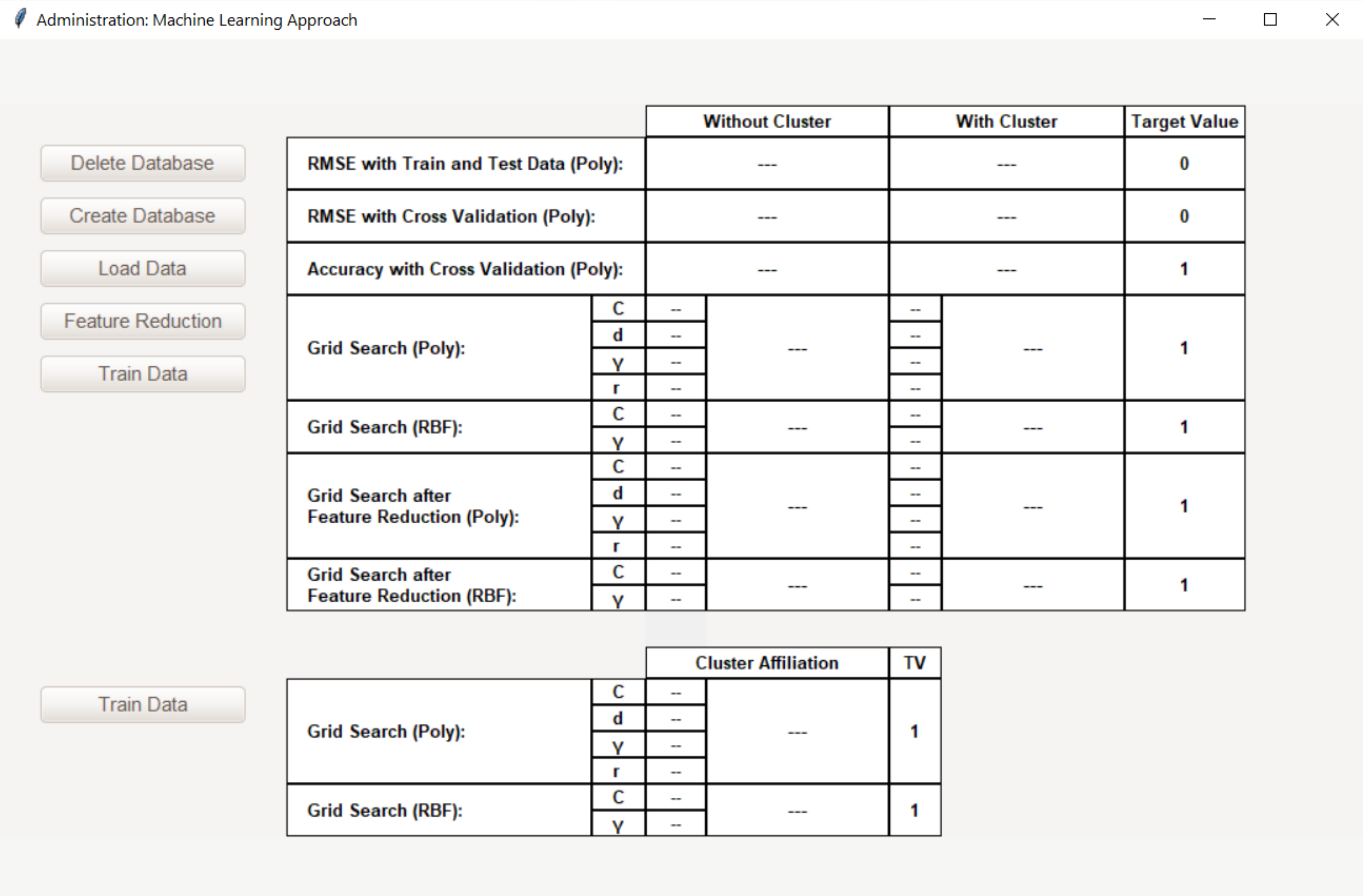


	A	B	C	D	E	F	G	H
1	sensing	acting_own	acting_inte	autonomy	direction	multiplicity	partner_use	partner_b
2	0.00	0.50	0.50	0.50	0.00	1.00	0.33	0.00
3	0.00	0.00	0.50	0.00	0.00	0.00	0.33	0.00
4	0.00	0.00	0.50	0.00	0.00	1.00	0.33	0.33
5	0.00	0.50	0.00	0.00	0.00	1.00	0.33	0.00
6	1.00	0.50	0.50	0.50	1.00	0.00	0.33	0.00
7	0.00	0.50	0.50	1.00	1.00	1.00	0.33	0.00
8	0.00	0.50	0.50	0.00	0.00	0.00	0.33	0.00
9	1.00	0.50	0.50	0.00	1.00	0.00	0.33	0.00
10	1.00	0.50	0.50	0.00	1.00	1.00	0.33	0.00
11	0.00	0.00	0.50	0.50	1.00	1.00	0.33	0.00
12	0.00	0.50	0.50	0.50	0.00	1.00	0.33	0.00
13	1.00	0.00	0.50	0.50	0.00	1.00	0.33	0.00
14	1.00	0.50	0.50	0.50	0.00	0.00	0.33	0.00
15	0.00	0.00	0.50	0.00	0.00	0.00	0.33	0.00
16	0.00	0.00	0.50	0.00	0.00	0.00	0.33	0.00
17	0.00	0.50	0.50	0.00	1.00	1.00	0.33	0.00
18	0.00	0.50	0.50	0.50	0.00	1.00	0.33	0.00
19	0.00	0.50	0.50	0.00	1.00	1.00	0.33	0.00
20	0.00	0.00	0.50	1.00	1.00	0.00	0.33	0.00
21	1.00	0.00	0.50	0.00	0.00	1.00	0.33	0.00
22	1.00	0.00	0.50	0.00	0.00	0.00	0.33	0.00

REALIZATION: THREE-LAYER ARCHITECTURE



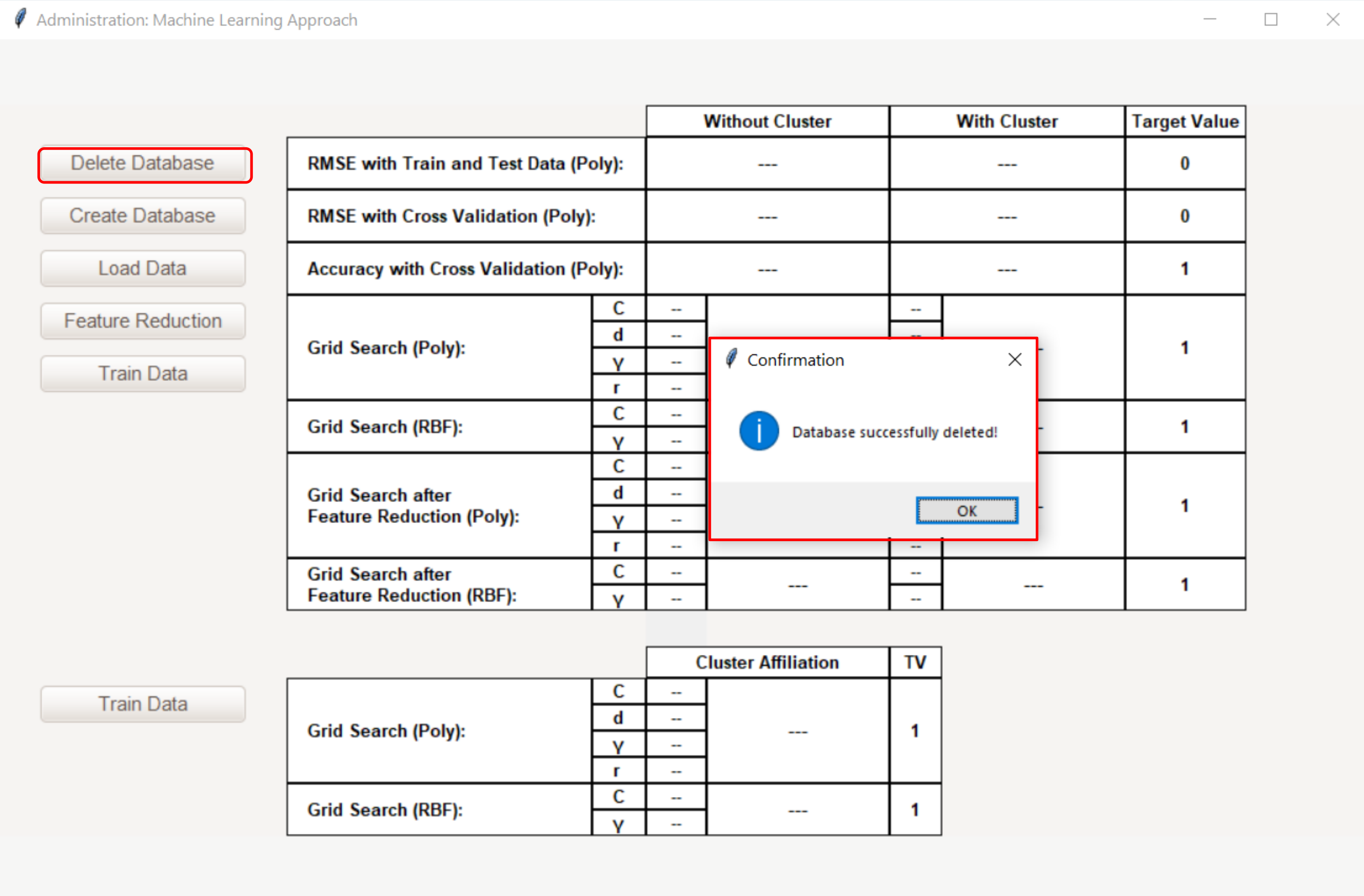
REALIZATION: BACKEND USER INTERFACE



		Without Cluster		With Cluster		Target Value
RMSE with Train and Test Data (Poly):		---		---		0
RMSE with Cross Validation (Poly):		---		---		0
Accuracy with Cross Validation (Poly):		---		---		1
Grid Search (Poly):	C	--	---	--	---	1
	d	--		--		
	γ	--		--		
	r	--		--		
Grid Search (RBF):	C	--	---	--	---	1
	γ	--		--		
Grid Search after Feature Reduction (Poly):	C	--	---	--	---	1
	d	--		--		
	γ	--		--		
	r	--		--		
Grid Search after Feature Reduction (RBF):	C	--	---	--	---	1
	γ	--		--		

		Cluster Affiliation		TV
Grid Search (Poly):	C	--	---	1
	d	--		
	γ	--		
	r	--		
Grid Search (RBF):	C	--	---	1
	γ	--		

REALIZATION: BACKEND USER INTERFACE



Administration: Machine Learning Approach

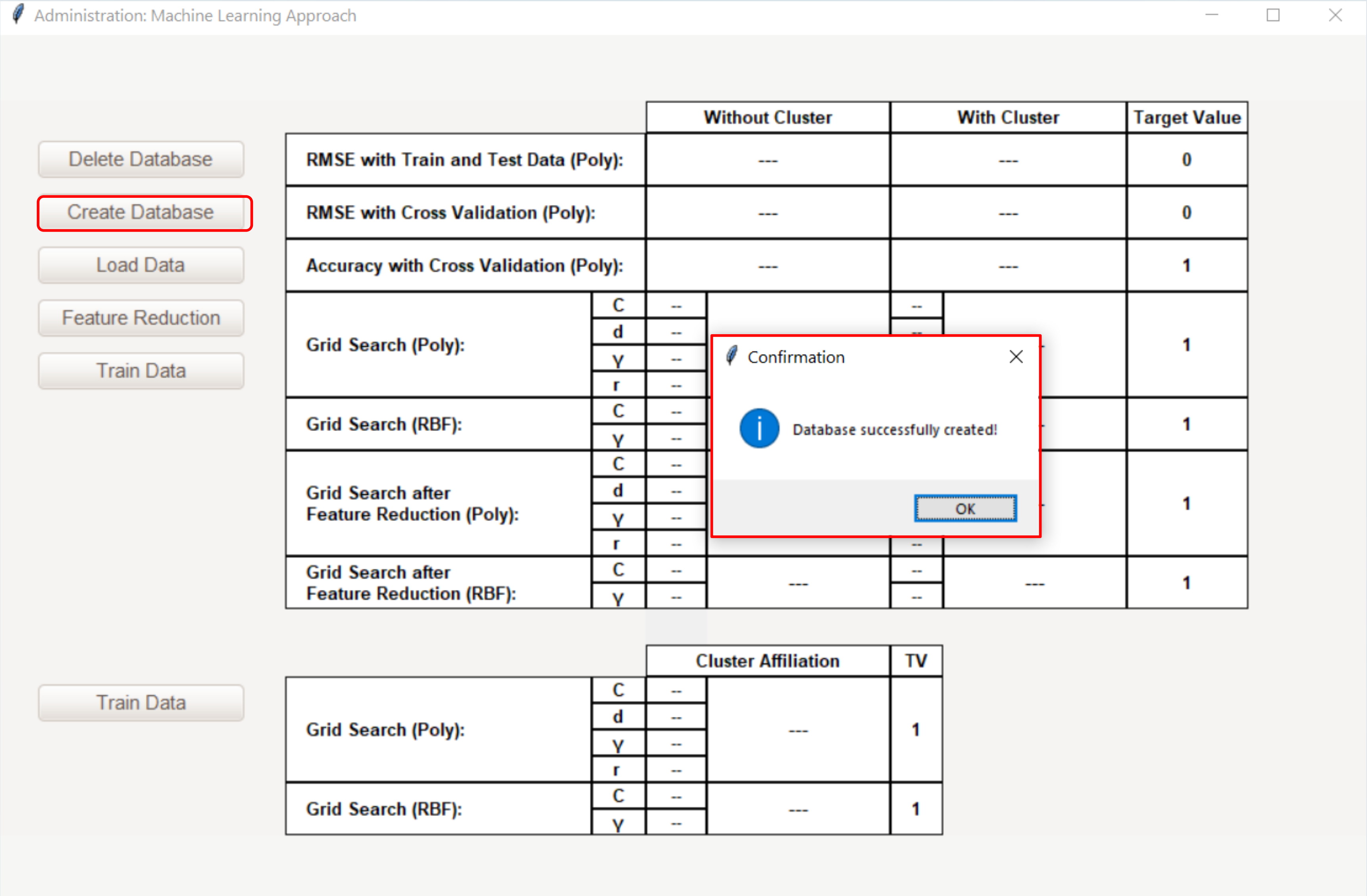
		Without Cluster		With Cluster		Target Value
RMSE with Train and Test Data (Poly):		---		---		0
RMSE with Cross Validation (Poly):		---		---		0
Accuracy with Cross Validation (Poly):		---		---		1
Grid Search (Poly):	C	--		--		1
	d	--		--		
	γ	--				
	r	--				
Grid Search (RBF):	C	--				1
	γ	--				
Grid Search after Feature Reduction (Poly):	C	--				1
	d	--				
	γ	--				
	r	--		--		
Grid Search after Feature Reduction (RBF):	C	--	---	--	---	1
	γ	--		--		

Confirmation

Database successfully deleted!

			Cluster Affiliation	TV
Grid Search (Poly):	C	--	---	1
	d	--		
	γ	--		
	r	--		
Grid Search (RBF):	C	--	---	1
	γ	--		

REALIZATION: BACKEND USER INTERFACE

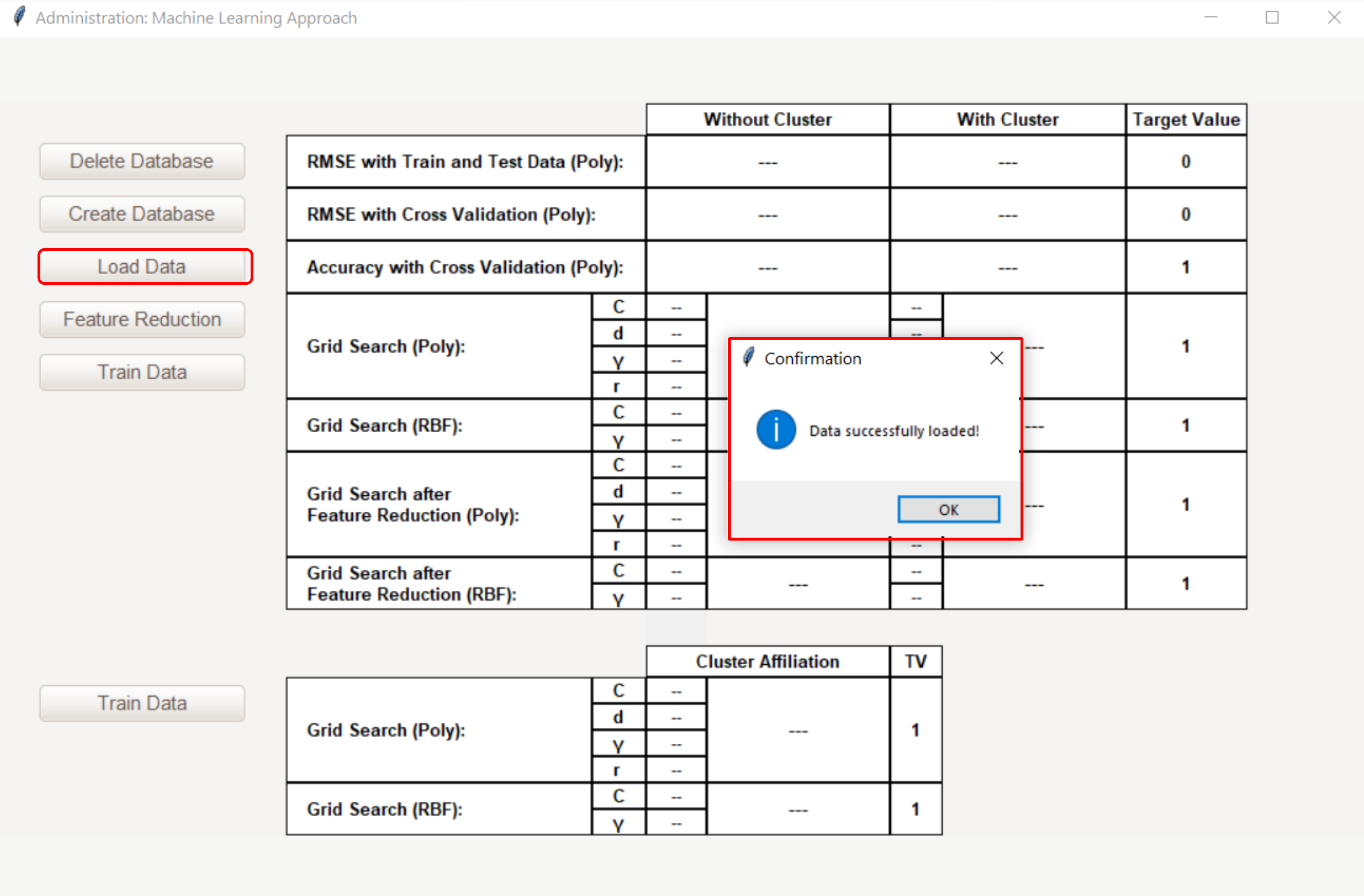


			Without Cluster		With Cluster	Target Value
RMSE with Train and Test Data (Poly):			---		---	0
RMSE with Cross Validation (Poly):			---		---	0
Accuracy with Cross Validation (Poly):			---		---	1
Grid Search (Poly):	C	--		--		1
	d	--				
	γ	--				
	r	--				
Grid Search (RBF):	C	--				1
	γ	--				
Grid Search after Feature Reduction (Poly):	C	--				1
	d	--				
	γ	--				
	r	--		--		
Grid Search after Feature Reduction (RBF):	C	--	---	--	---	1
	γ	--		--		

Database successfully created!

			Cluster Affiliation	TV
Grid Search (Poly):	C	--	---	1
	d	--		
	γ	--		
	r	--		
Grid Search (RBF):	C	--	---	1
	γ	--		

REALIZATION: BACKEND USER INTERFACE



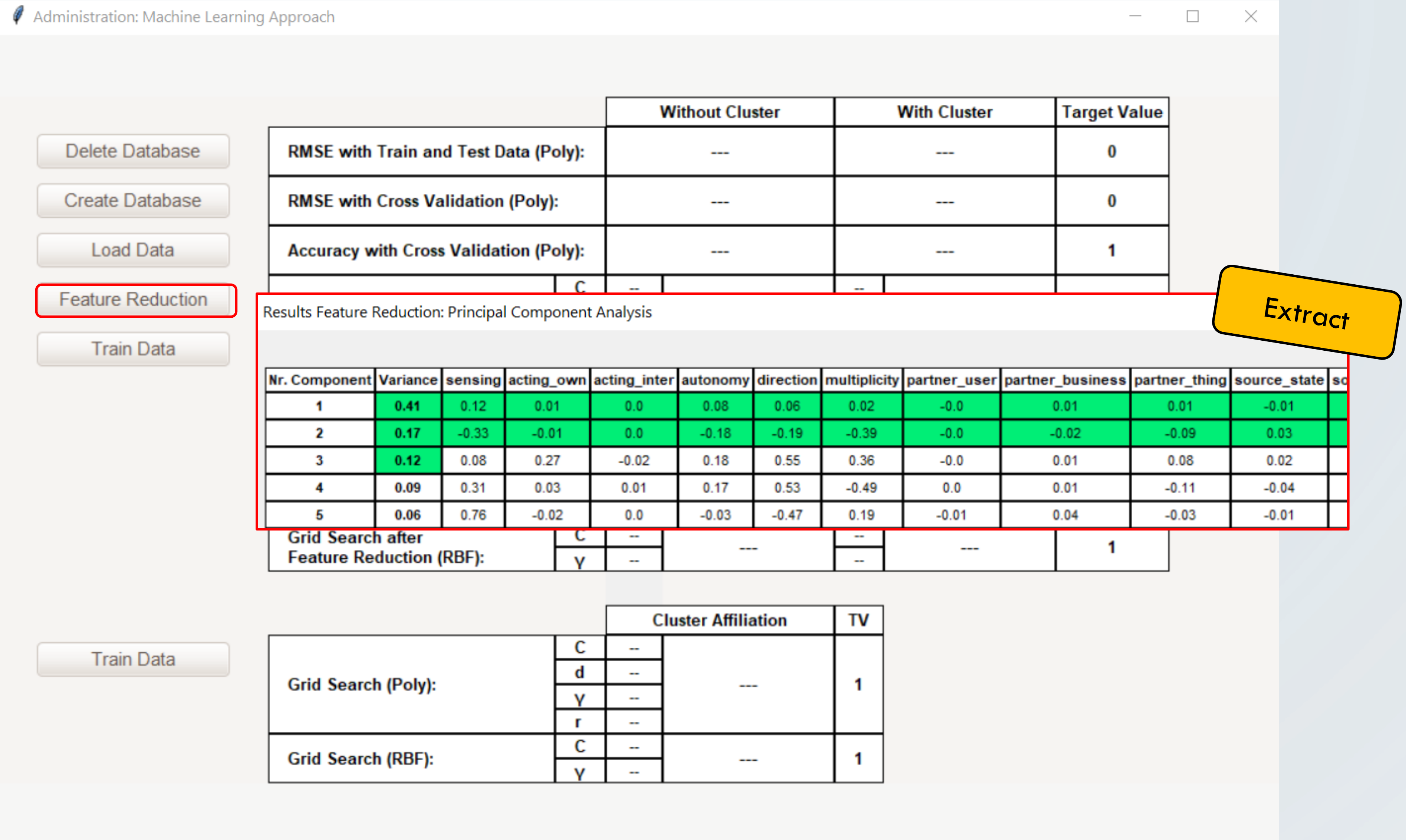
		Without Cluster		With Cluster		Target Value
RMSE with Train and Test Data (Poly):		---		---		0
RMSE with Cross Validation (Poly):		---		---		0
Accuracy with Cross Validation (Poly):		---		---		1
Grid Search (Poly):	C	--		--	---	1
	d	--		--		
	γ	--				
	r	--				
Grid Search (RBF):	C	--			---	1
	γ	--				
Grid Search after Feature Reduction (Poly):	C	--			---	1
	d	--				
	γ	--				
	r	--		--		
Grid Search after Feature Reduction (RBF):	C	--	---	--	---	1
	γ	--		--		

Confirmation

Data successfully loaded!

		Cluster Affiliation		TV
Grid Search (Poly):	C	--	---	1
	d	--		
	γ	--		
	r	--		
Grid Search (RBF):	C	--	---	1
	γ	--		

REALIZATION: BACKEND USER INTERFACE



			Without Cluster		With Cluster	Target Value
RMSE with Train and Test Data (Poly):			---		---	0
RMSE with Cross Validation (Poly):			---		---	0
Accuracy with Cross Validation (Poly):			---		---	1
	C	--		--		
Grid Search after Feature Reduction (RBF):	C γ	-- --	---	-- --	---	1

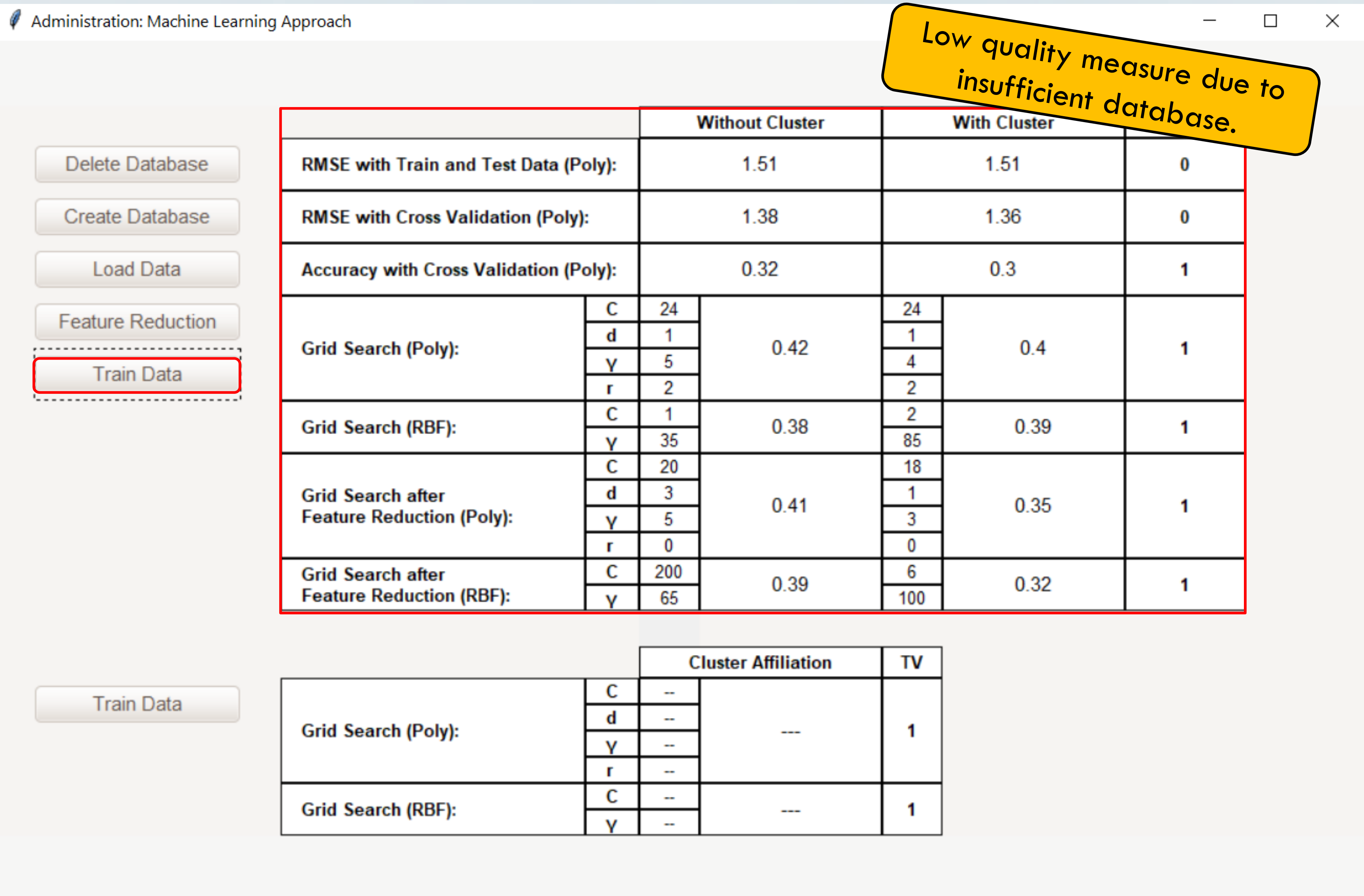
Extract

Results Feature Reduction: Principal Component Analysis

Nr. Component	Variance	sensing	acting_own	acting_inter	autonomy	direction	multiplicity	partner_user	partner_business	partner_thing	source_state	so
1	0.41	0.12	0.01	0.0	0.08	0.06	0.02	-0.0	0.01	0.01	-0.01	
2	0.17	-0.33	-0.01	0.0	-0.18	-0.19	-0.39	-0.0	-0.02	-0.09	0.03	
3	0.12	0.08	0.27	-0.02	0.18	0.55	0.36	-0.0	0.01	0.08	0.02	
4	0.09	0.31	0.03	0.01	0.17	0.53	-0.49	0.0	0.01	-0.11	-0.04	
5	0.06	0.76	-0.02	0.0	-0.03	-0.47	0.19	-0.01	0.04	-0.03	-0.01	

			Cluster Affiliation	TV
Grid Search (Poly):	C d γ r	-- -- -- --	---	1
Grid Search (RBF):	C γ	-- --	---	1

REALIZATION: BACKEND USER INTERFACE

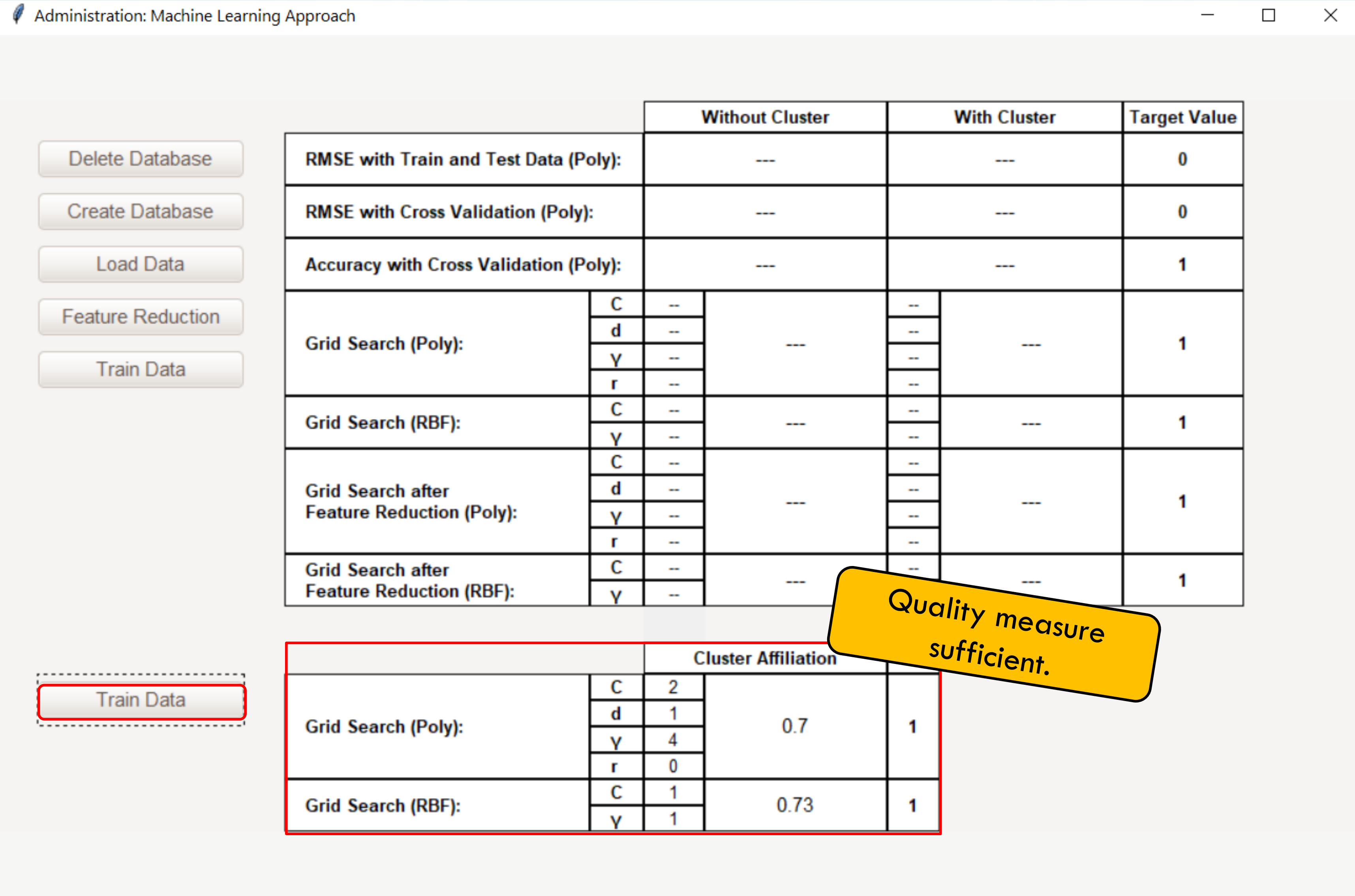


Low quality measure due to insufficient database.

		Without Cluster		With Cluster		
RMSE with Train and Test Data (Poly):		1.51		1.51		0
RMSE with Cross Validation (Poly):		1.38		1.36		0
Accuracy with Cross Validation (Poly):		0.32		0.3		1
Grid Search (Poly):	C	24	0.42	24	0.4	1
	d	1		1		
	γ	5		4		
	r	2		2		
Grid Search (RBF):	C	1	0.38	2	0.39	1
	γ	35		85		
Grid Search after Feature Reduction (Poly):	C	20	0.41	18	0.35	1
	d	3		1		
	γ	5		3		
	r	0		0		
Grid Search after Feature Reduction (RBF):	C	200	0.39	6	0.32	1
	γ	65		100		

		Cluster Affiliation		TV
Grid Search (Poly):	C	--	---	1
	d	--		
	γ	--		
	r	--		
Grid Search (RBF):	C	--	---	1
	γ	--		

REALIZATION: BACKEND USER INTERFACE

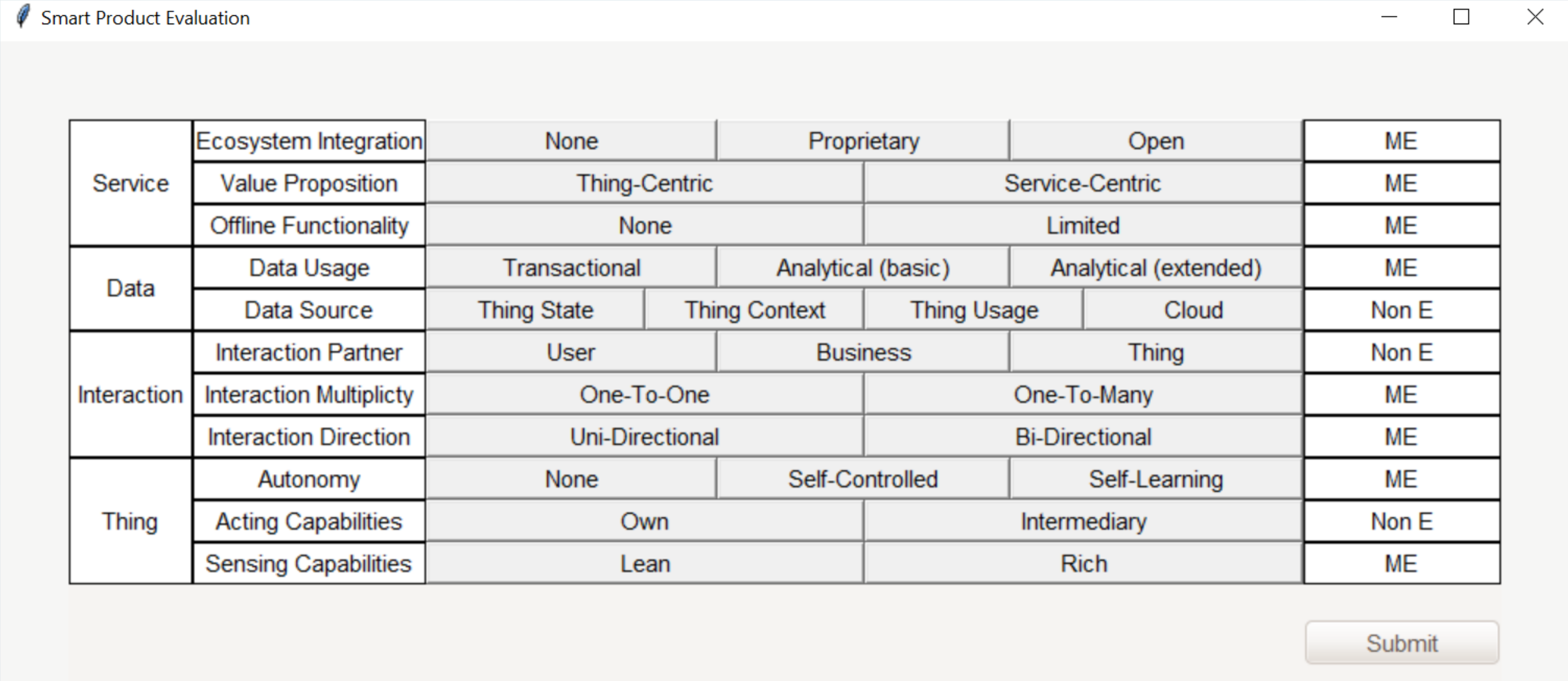


		Without Cluster		With Cluster		Target Value
RMSE with Train and Test Data (Poly):		---		---		0
RMSE with Cross Validation (Poly):		---		---		0
Accuracy with Cross Validation (Poly):		---		---		1
Grid Search (Poly):	C	--	---	--	---	1
	d	--		--		
	γ	--		--		
	r	--		--		
Grid Search (RBF):	C	--	---	--	---	1
	γ	--		--		
Grid Search after Feature Reduction (Poly):	C	--	---	--	---	1
	d	--		--		
	γ	--		--		
	r	--		--		
Grid Search after Feature Reduction (RBF):	C	--	---	--	---	1
	γ	--		--		

		Cluster Affiliation		
Grid Search (Poly):	C	2	0.7	1
	d	1		
	γ	4		
	r	0		
Grid Search (RBF):	C	1	0.73	1
	γ	1		

Quality measure sufficient.

REALIZATION: FRONTEND USER INTERFACE



Service	Ecosystem Integration	None	Proprietary	Open		ME
	Value Proposition	Thing-Centric	Service-Centric			ME
	Offline Functionality	None	Limited			ME
Data	Data Usage	Transactional	Analytical (basic)	Analytical (extended)		ME
	Data Source	Thing State	Thing Context	Thing Usage	Cloud	Non E
Interaction	Interaction Partner	User	Business	Thing		Non E
	Interaction Multiplicty	One-To-One	One-To-Many			ME
	Interaction Direction	Uni-Directional	Bi-Directional			ME
Thing	Autonomy	None	Self-Controlled	Self-Learning		ME
	Acting Capabilities	Own	Intermediary			Non E
	Sensing Capabilities	Lean	Rich			ME

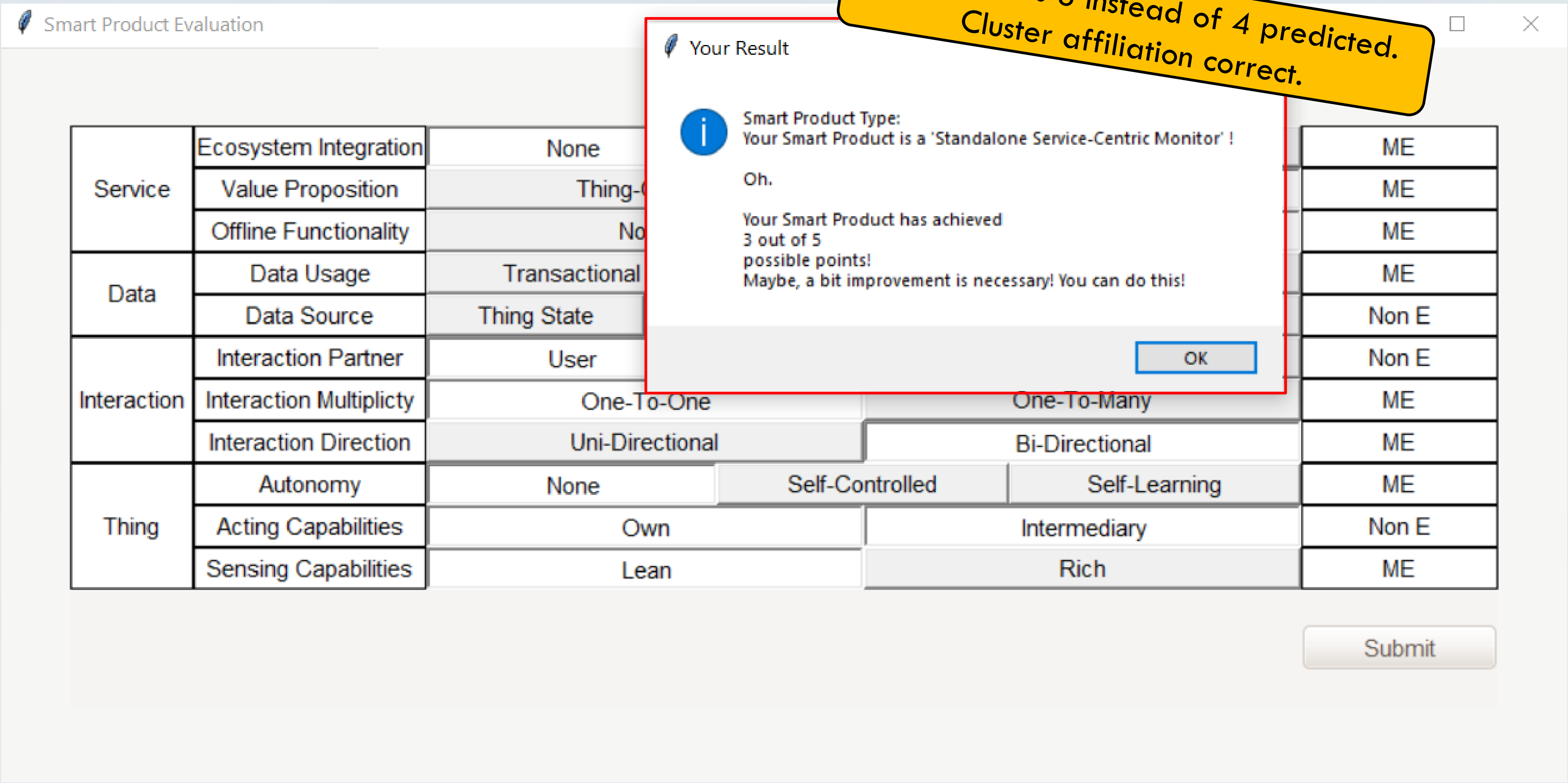
SHOW CASE USING THE EXAMPLE „FITBIT“

	Dimension	Characteristics			
Service	Ecosystem Integration	[✓ None]	Proprietary	Open	
	Value Proposition	Thing-centric	[✓ Service-centric]		
	Offline Functionality	None	[✓ Limited]		
Data	Data Usage	Transactional	[✓ Analytical (basic)]	Analytical (extended)	
	Data Source	Thing State	Thing Context	[✓ Thing Usage]	Cloud
Interaction	Interaction Partner	[✓ User(s)]	Business(es)	Thing(s)	
	Interaction Multiplicity	[✓ One-to-one]	One-to-many		
	Interaction Direction	Unidirectional	[✓ Bi-directional]		
Thing	Autonomy	[✓ None]	Self-Controlled	Self-Learning	
	Acting Capabilities	[✓ Own]	[✓ Intermediary]		
	Sensing Capabilities	[✓ Lean]	Rich		

Success: Classes 1 to 5. Devices in class **5 most successful**. **Fitbit** in **class 4**, was **not part of** the **training data set**.

REALIZATION: FRONTEND USER INTERFACE

Success class 3 instead of 4 predicted.
Cluster affiliation correct.



Smart Product Type:
Your Smart Product is a 'Standalone Service-Centric Monitor' !

Oh.

Your Smart Product has achieved
3 out of 5
possible points!
Maybe, a bit improvement is necessary! You can do this!

Service	Ecosystem Integration	None			ME
	Value Proposition	Thing-(			ME
	Offline Functionality	No			ME
Data	Data Usage	Transactional			ME
	Data Source	Thing State			Non E
Interaction	Interaction Partner	User			Non E
	Interaction Multiplicty	One-To-One	One-To-Many		ME
	Interaction Direction	Uni-Directional	Bi-Directional		ME
Thing	Autonomy	None	Self-Controlled	Self-Learning	ME
	Acting Capabilities	Own	Intermediary		Non E
	Sensing Capabilities	Lean	Rich		ME

CONCLUSION

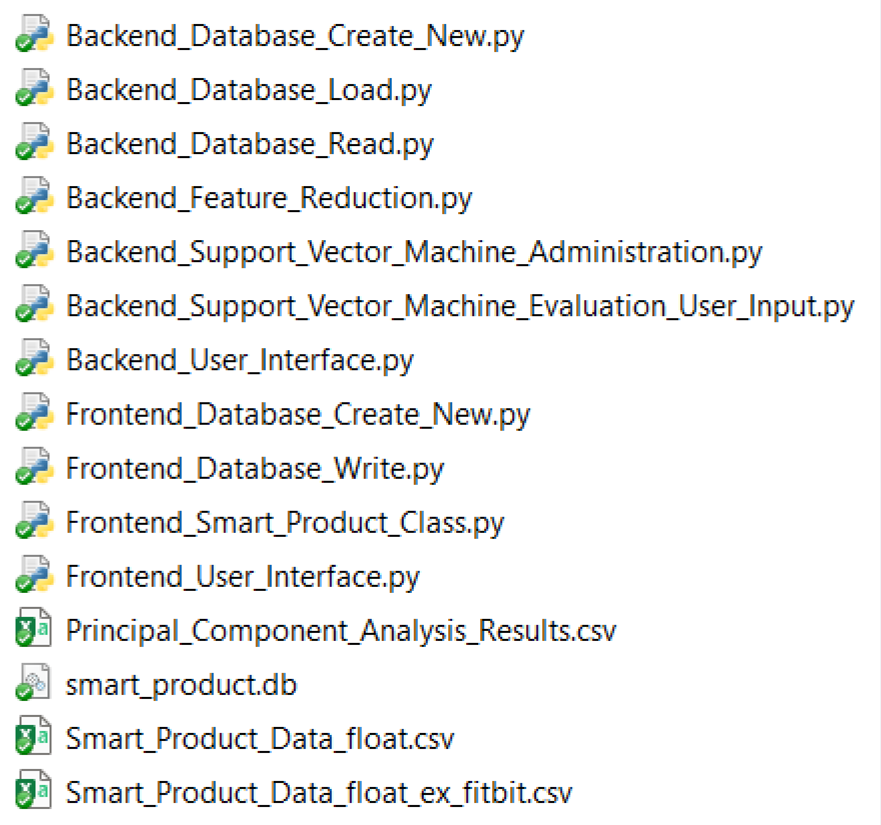
Learnings

- **Improvement of quality measures necessary** for the success of Smart Things
- Possible **reasons** for **insufficient results**:
  - **Too many features** (i.e. characteristics)
  - **Extension** of the **data set** by further Smart Things to achieve a representative sample
  - **Devices** with **similar characteristics** have **different degrees of success**

- Quality measures for **cluster allocation achieve good results.** Thus, assignment based on user input is possible

- **Evaluation** in comparison **with other methods** (e.g. neural networks)

OVERVIEW FILES CREATED DURING THE PROJECT



Backend_Database_Create_New.py
Backend_Database_Load.py
Backend_Database_Read.py
Backend_Feature_Reduction.py
Backend_Support_Vector_Machine_Administration.py
Backend_Support_Vector_Machine_Evaluation_User_Input.py
Backend_User_Interface.py
Frontend_Database_Create_New.py
Frontend_Database_Write.py
Frontend_Smart_Product_Class.py
Frontend_User_Interface.py
Principal_Component_Analysis_Results.csv
smart_product.db
Smart_Product_Data_float.csv
Smart_Product_Data_float_ex_fitbit.csv