Visualization and Exploration of Optimal Variants in Product Line Engineering (PLE)

Alexandr Murashkin
Michał Antkiewicz
Derek Rayside
Krzysztof Czarnecki

University of Waterloo, Canada

International Software Product Line Conference '17, Tokyo, Japan, 2013

Optimization in Product Line Engineering (PLE)

1. A product line: Mobile Phones (`WiFi`, `USB`, `LTE`, Battery)

Optimization in Product Line Engineering (PLE)

1. A product line: Mobile Phones (`WiFi`, `USB`, `LTE`, Battery)

2. Product variants:


```
MobilePhone1
    LTE
    WiFi
    Battery
        Battery1400
```


```
MobilePhone2
    USB
    WiFi
    Battery
        Battery1150
```

Optimization in Product Line Engineering (PLE)

1. A product line: Mobile Phones (`WiFi`, `USB`, `LTE`, Battery)

2. Product variants:


```
MobilePhone1
    LTE
    WiFi
    Battery
        Battery1400
```


```
MobilePhone2
    USB
    WiFi
    Battery
        Battery1150
```

3. Quality attributes:

`LTE` (+4 to a variant's `cost`, +2 to `productivity`)

Optimization in Product Line Engineering (PLE): Challenge

- To discover **optimal variants** with respect to **objectives**:

  Minimize variant's `cost`

  Maximize `batterylife`

  Maximize `security`

  .....

Optimization in Product Line Engineering (PLE): Challenge

- To discover **optimal variants** with respect to **objectives**:

  Minimize variant's `cost`

  Maximize `batterylife`

  Maximize `security`

  .....

Optimization in Product Line Engineering (PLE): Challenge

- To discover **optimal variants** with respect to **objectives**:

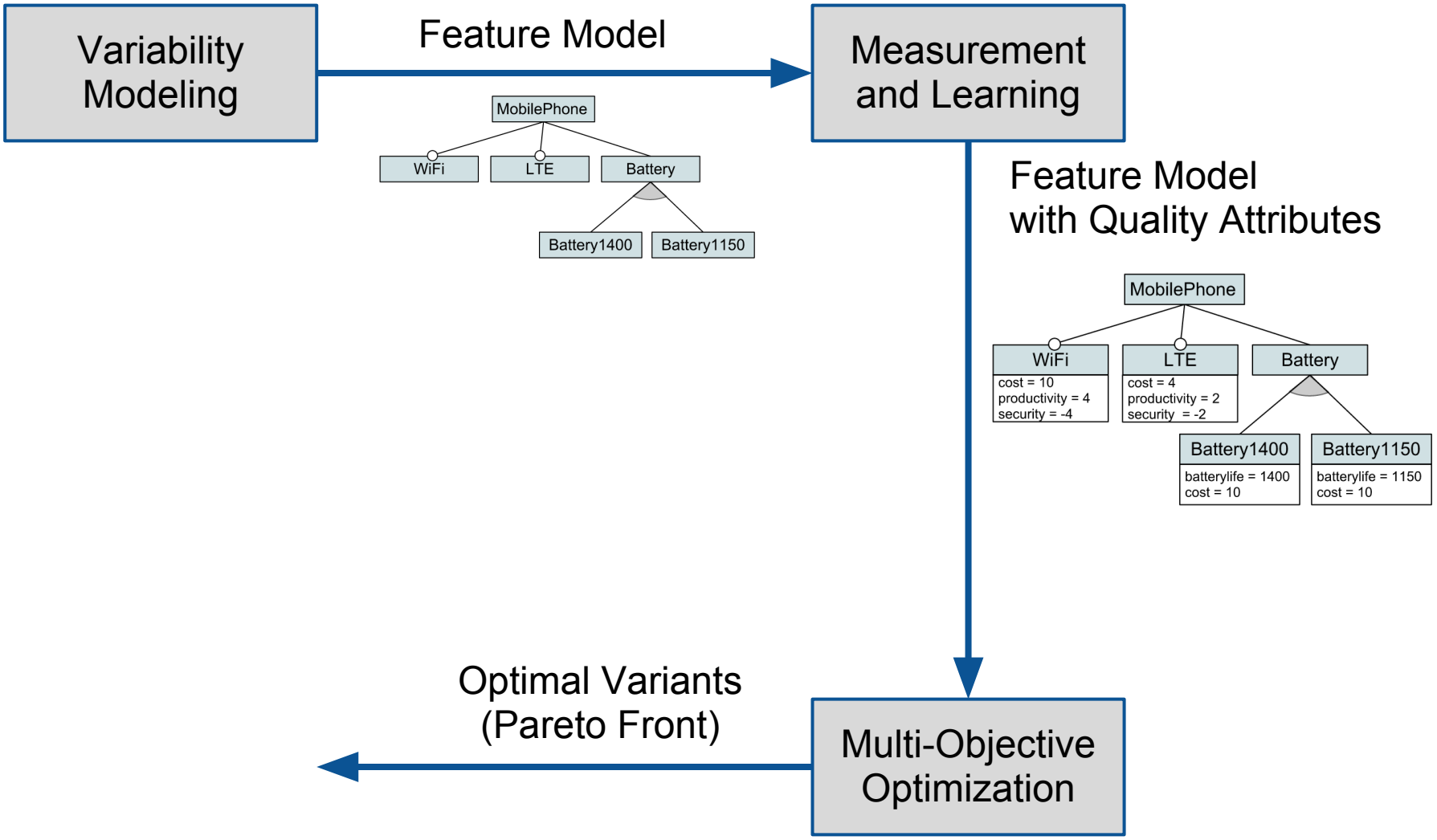
  Minimize variant's `cost`

  Maximize `batterylife`

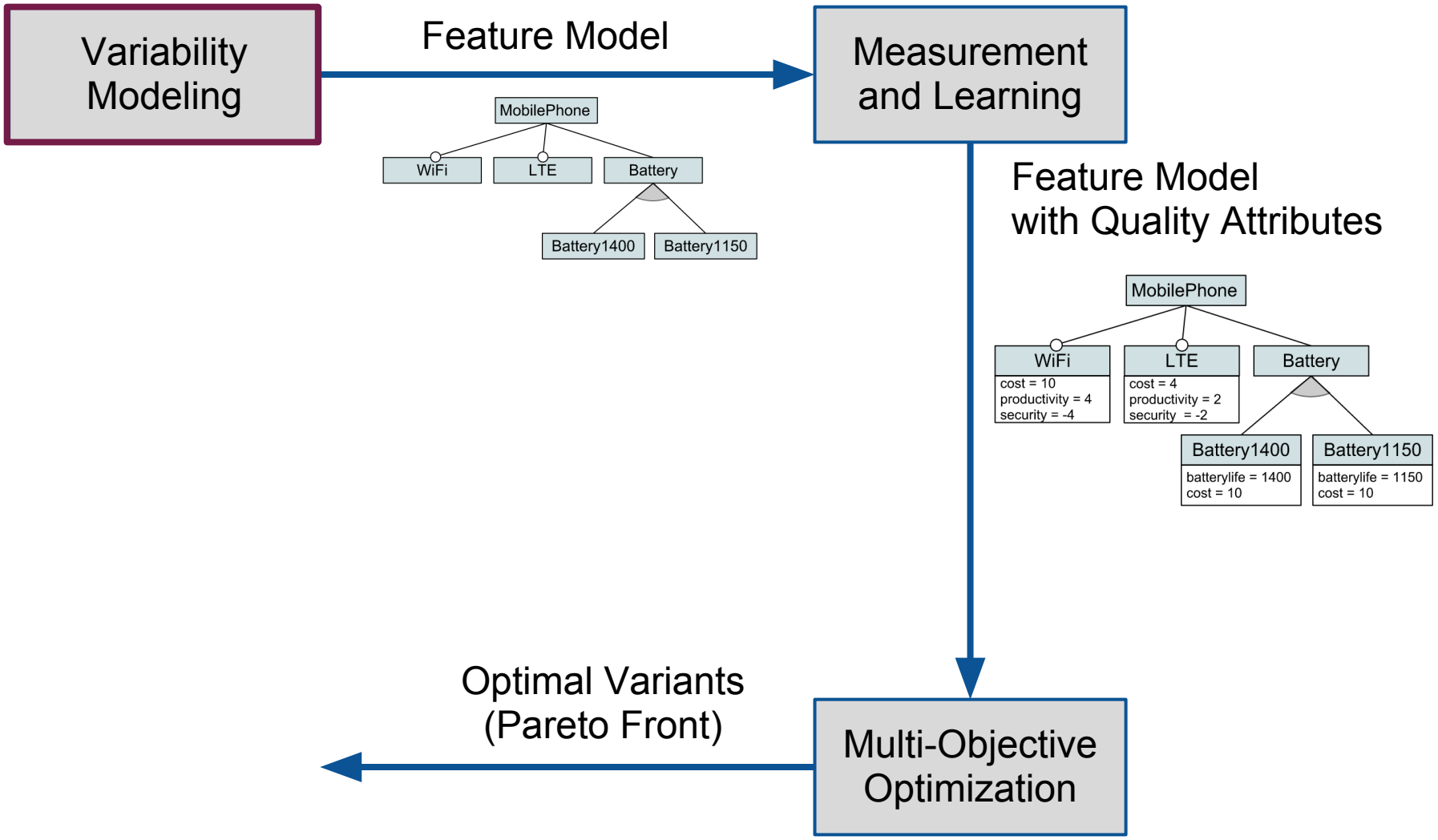
  Maximize `security`

  .....

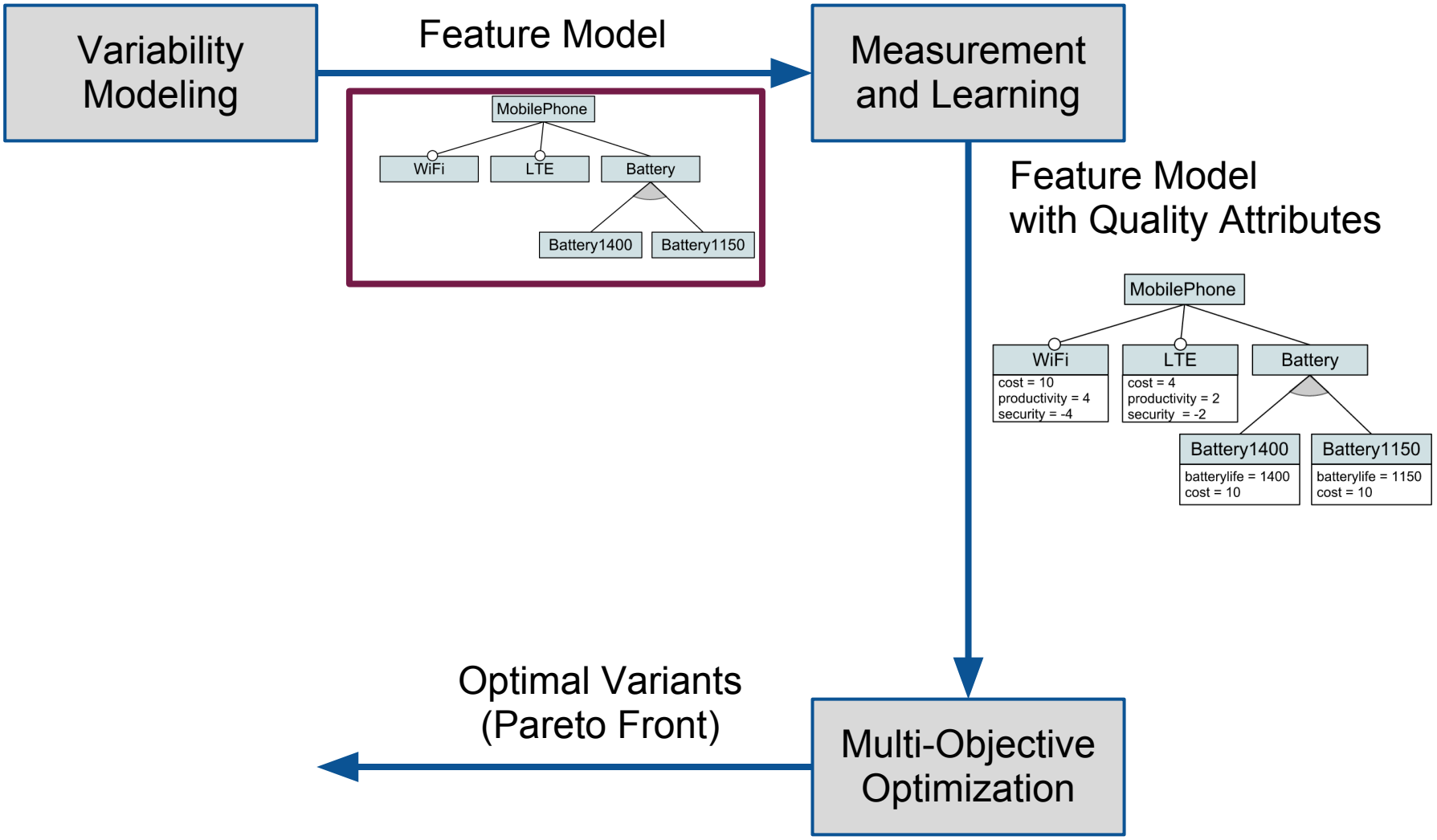
Optimization Workflow in PLE



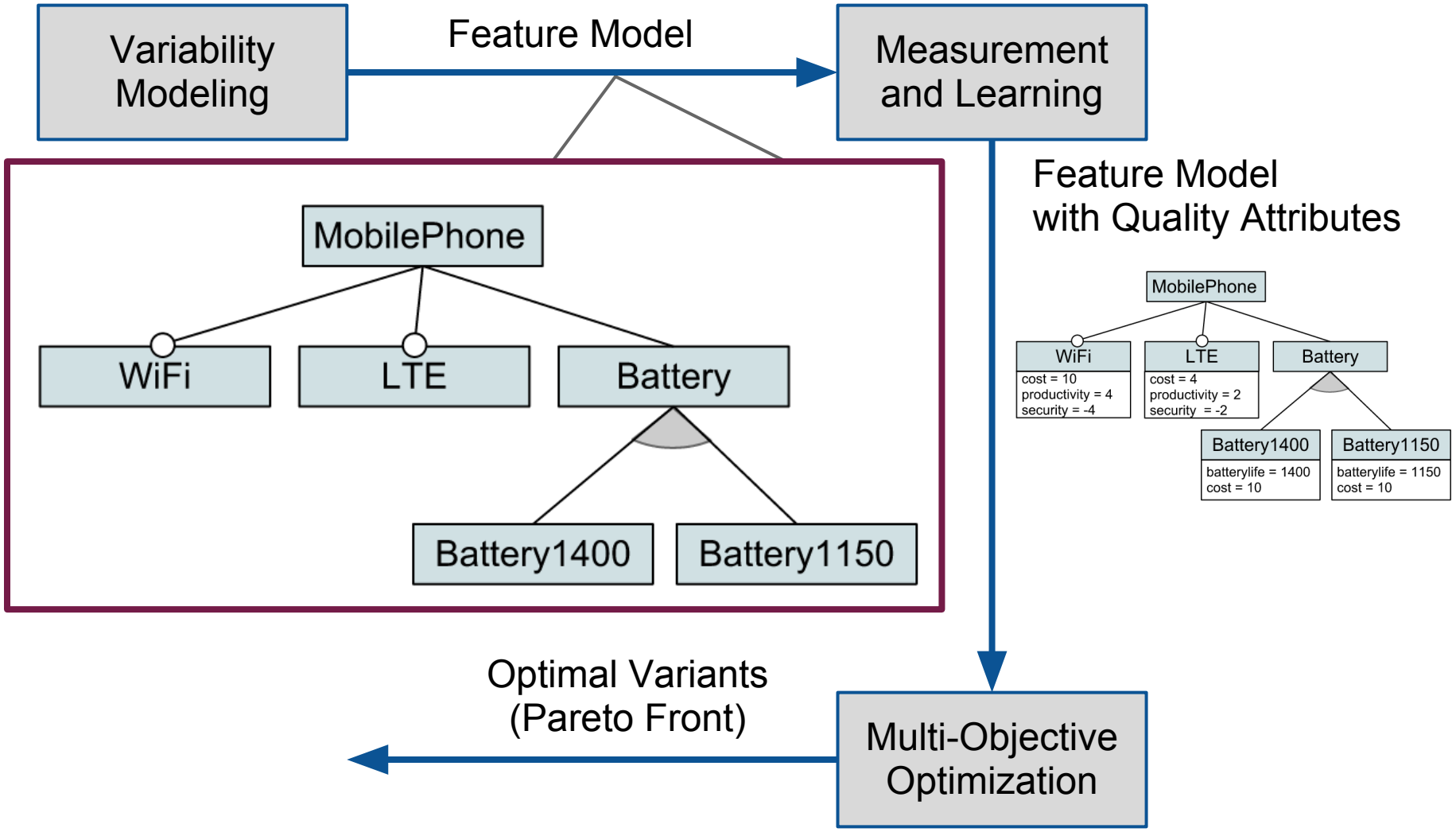
Optimization Workflow in PLE



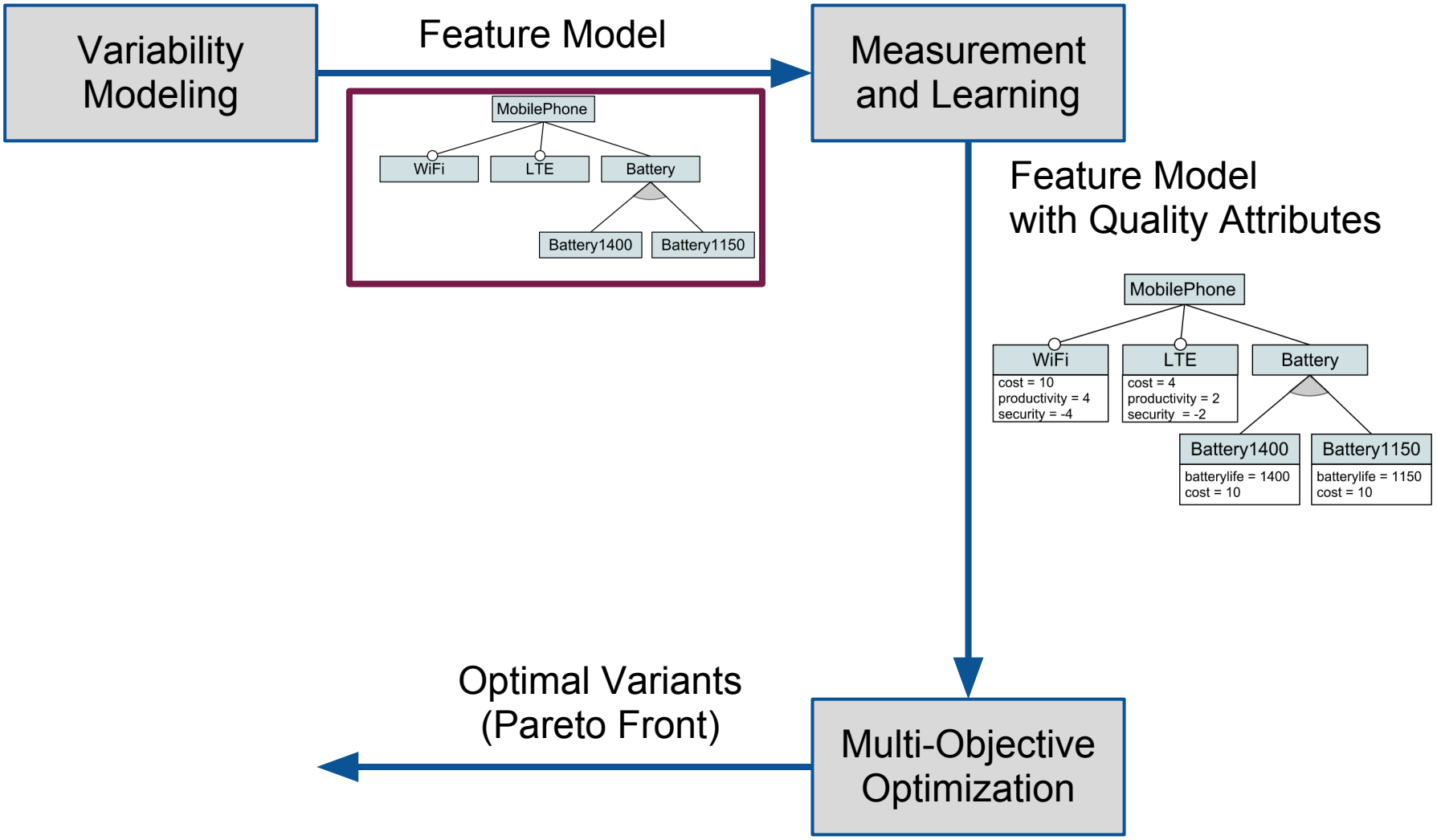
Optimization Workflow in PLE



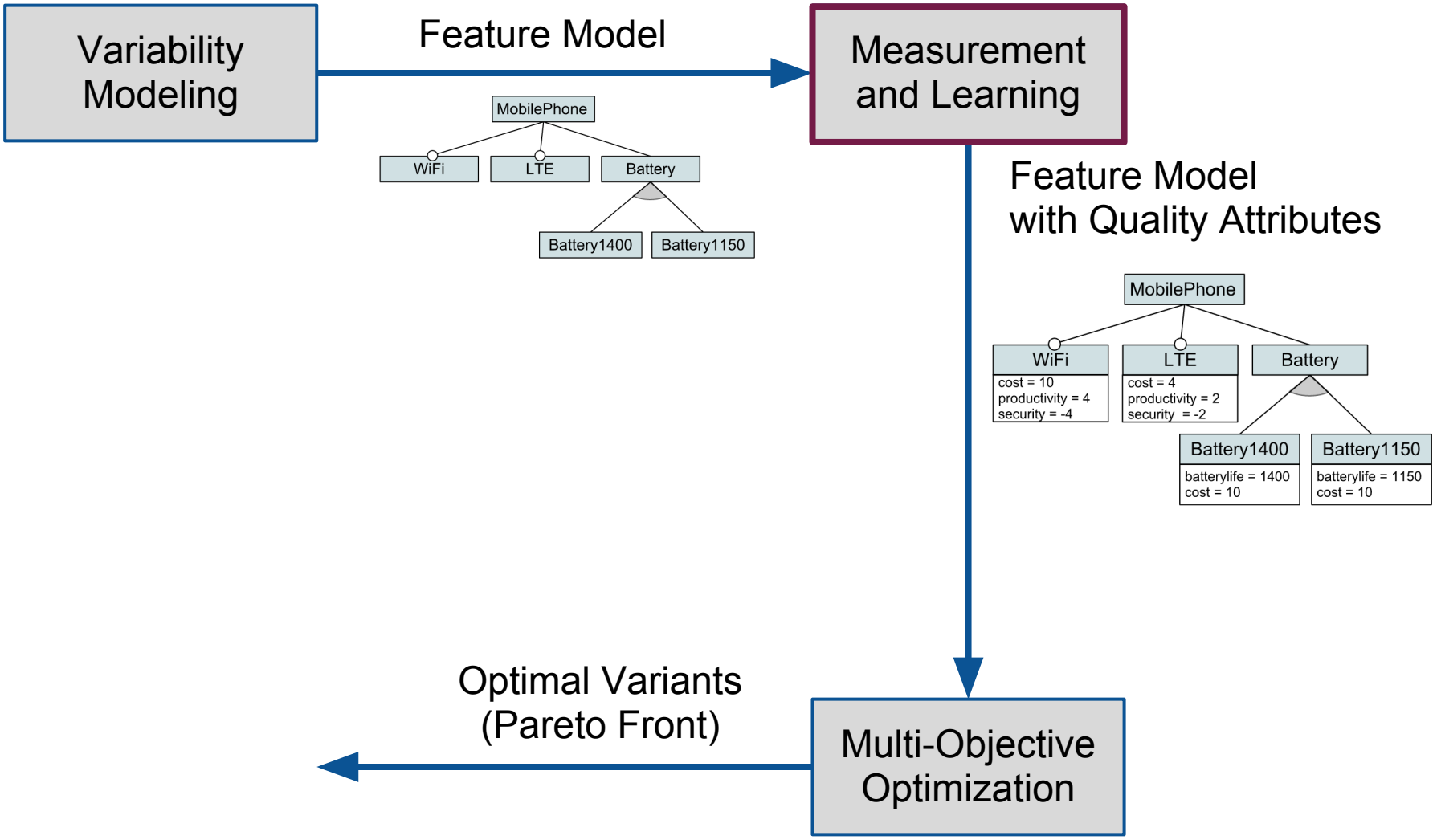
Optimization Workflow in PLE



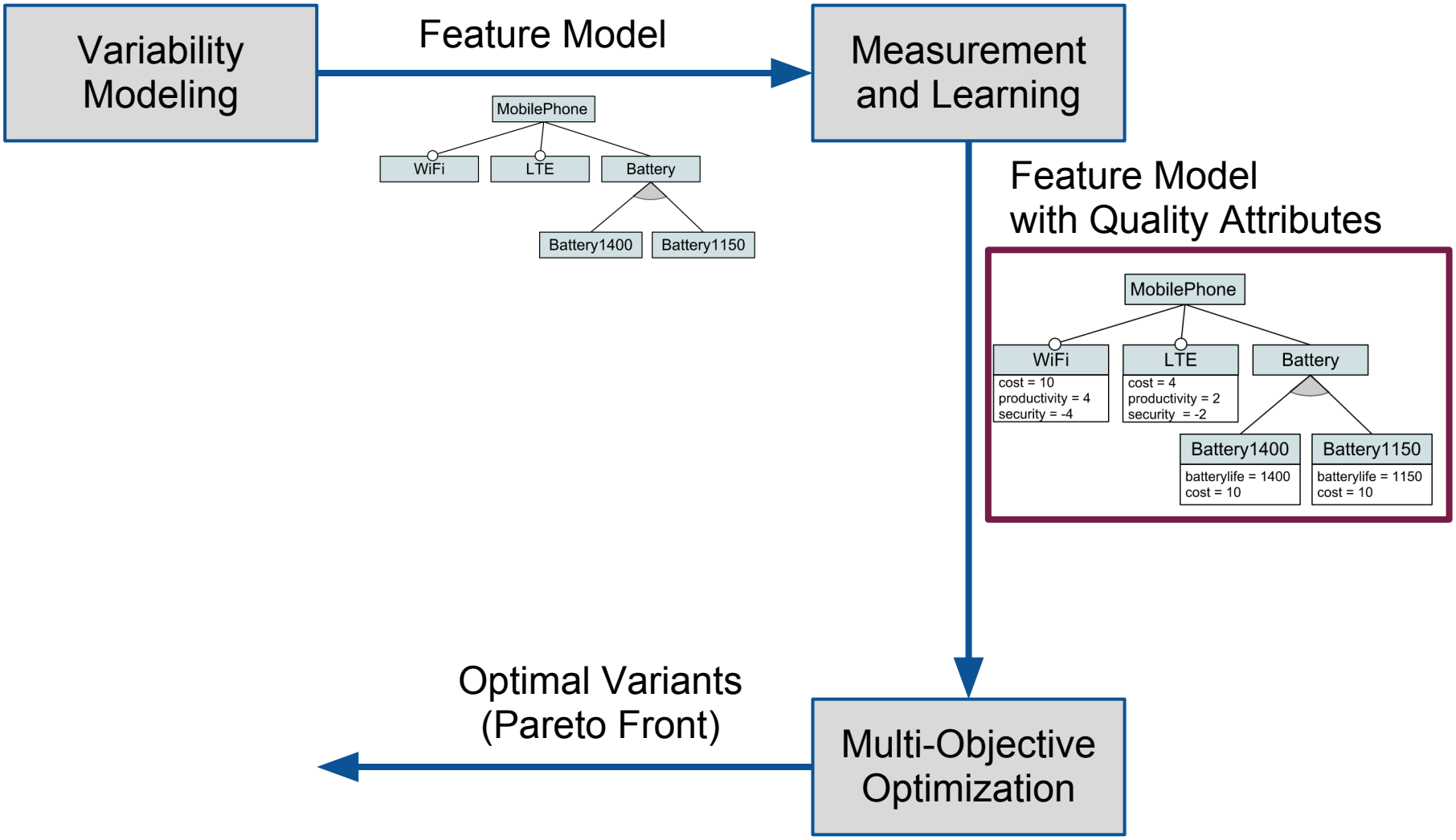
Optimization Workflow in PLE



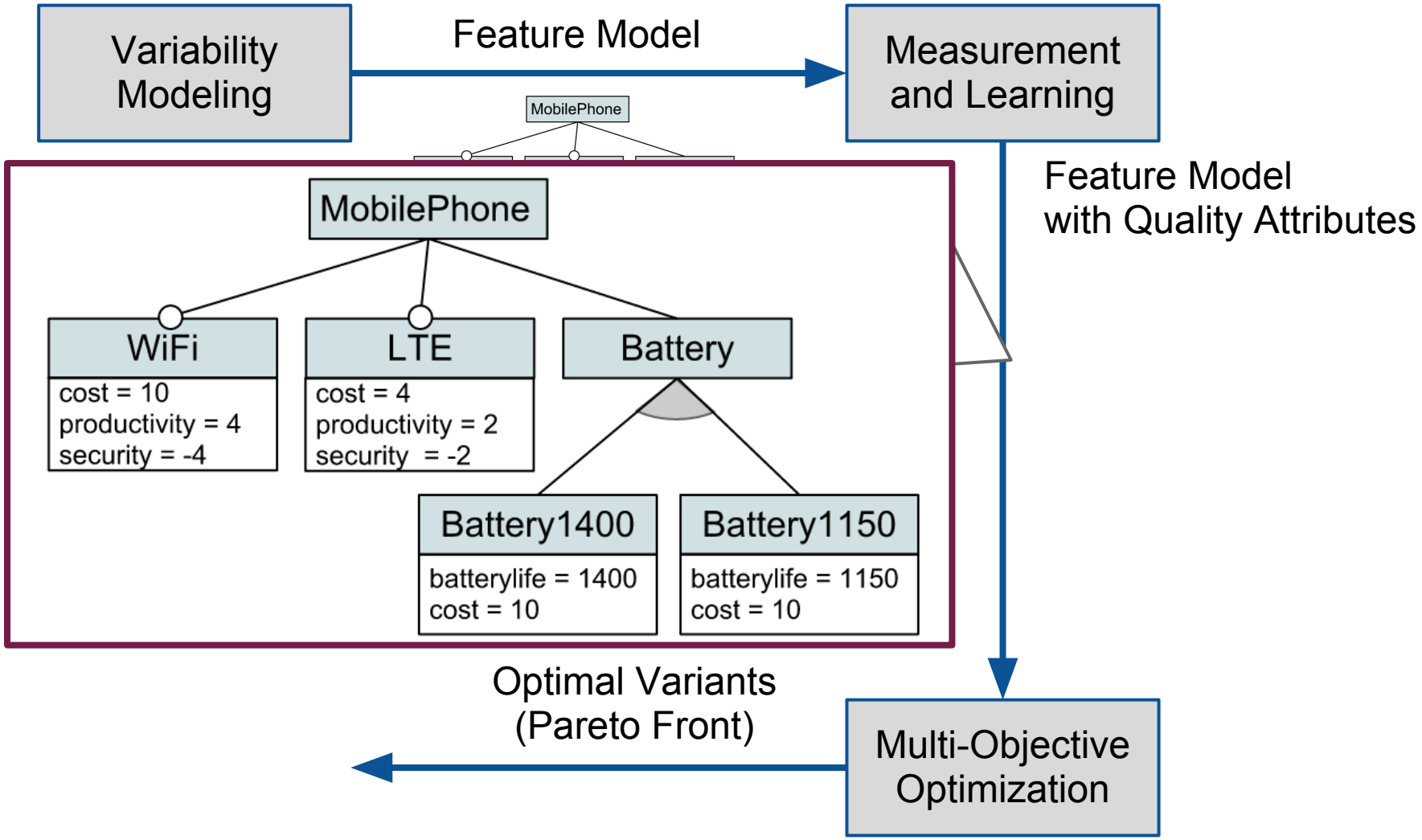
Optimization Workflow in PLE



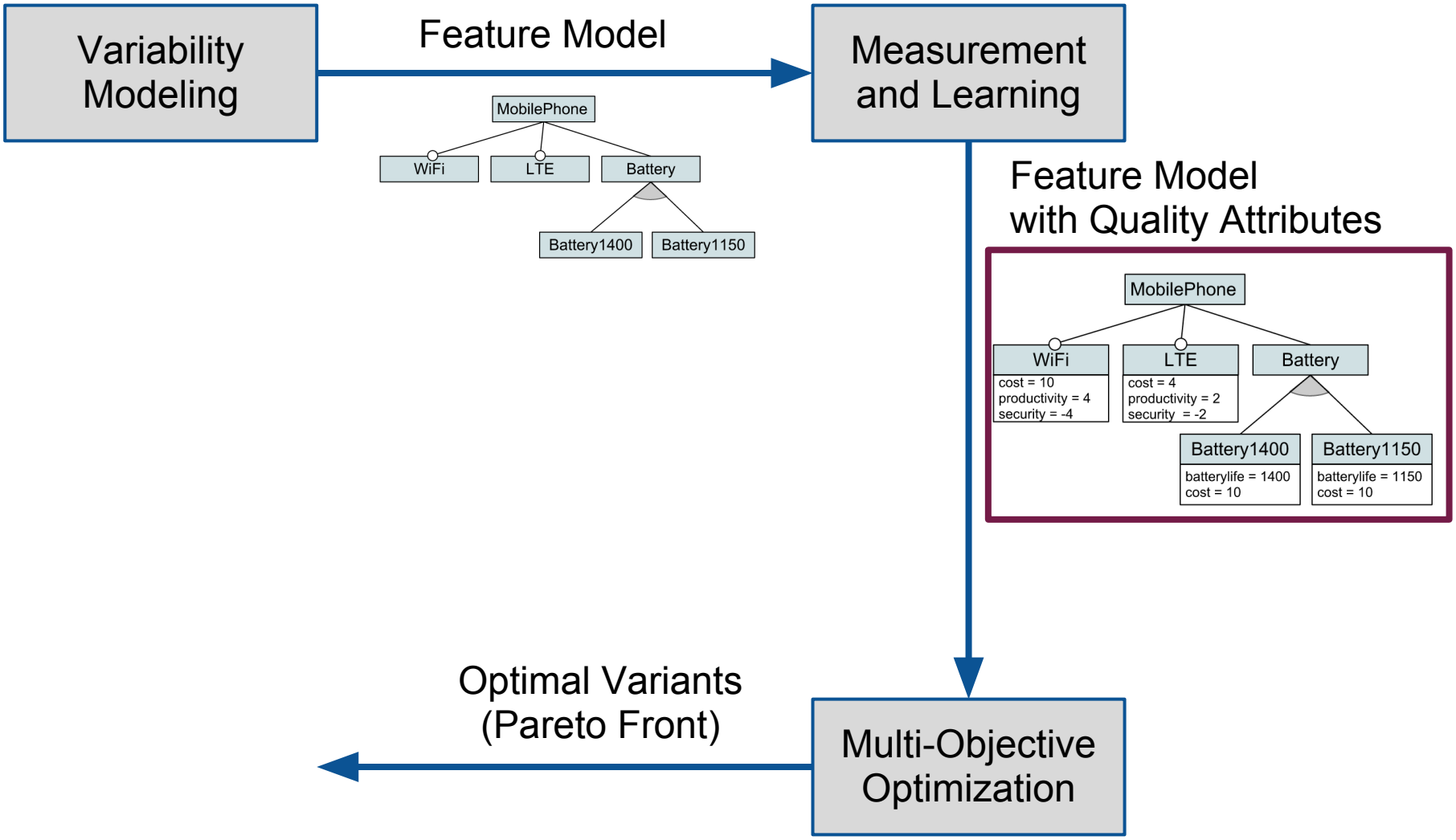
Optimization Workflow in PLE



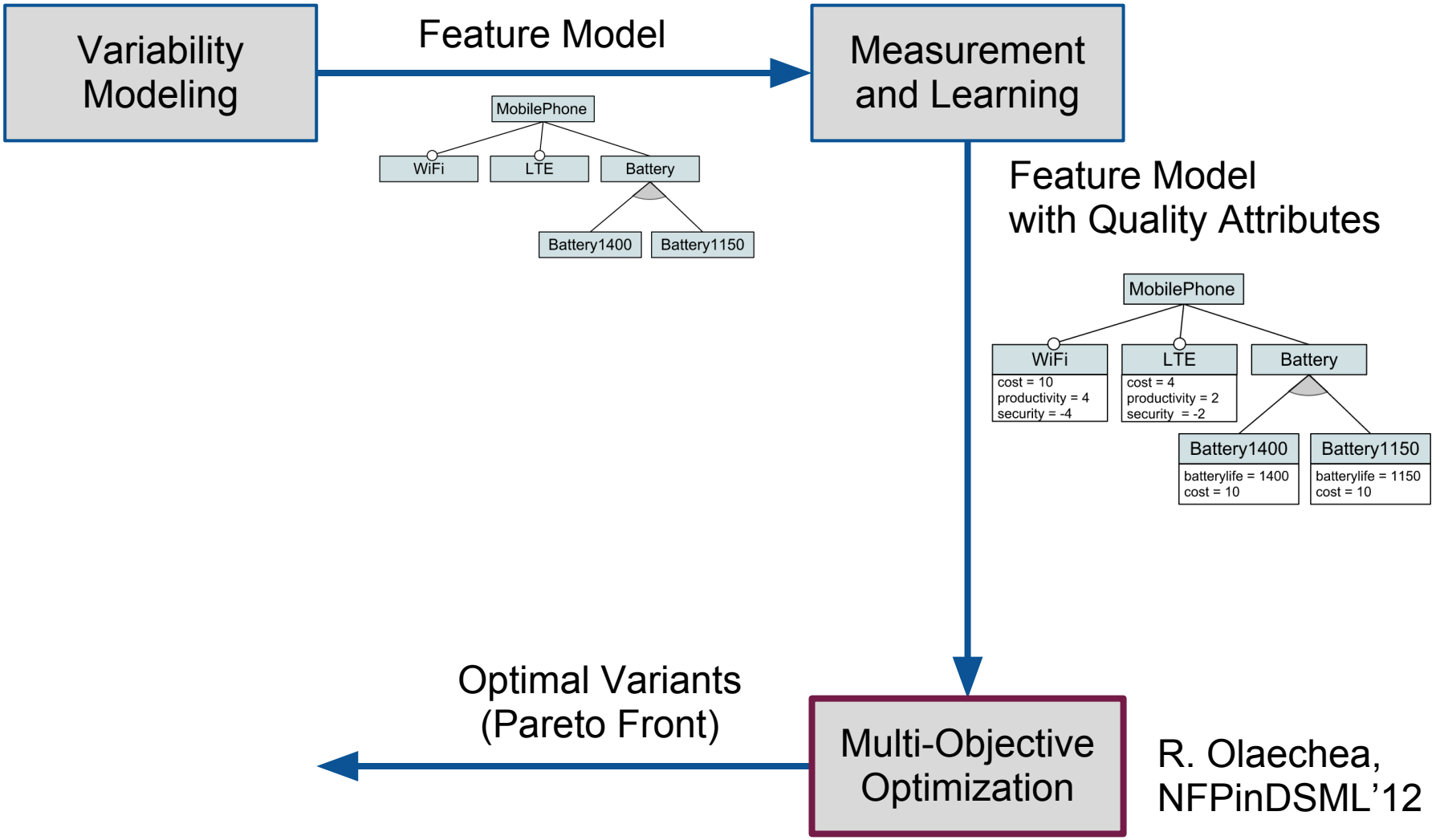
Optimization Workflow in PLE



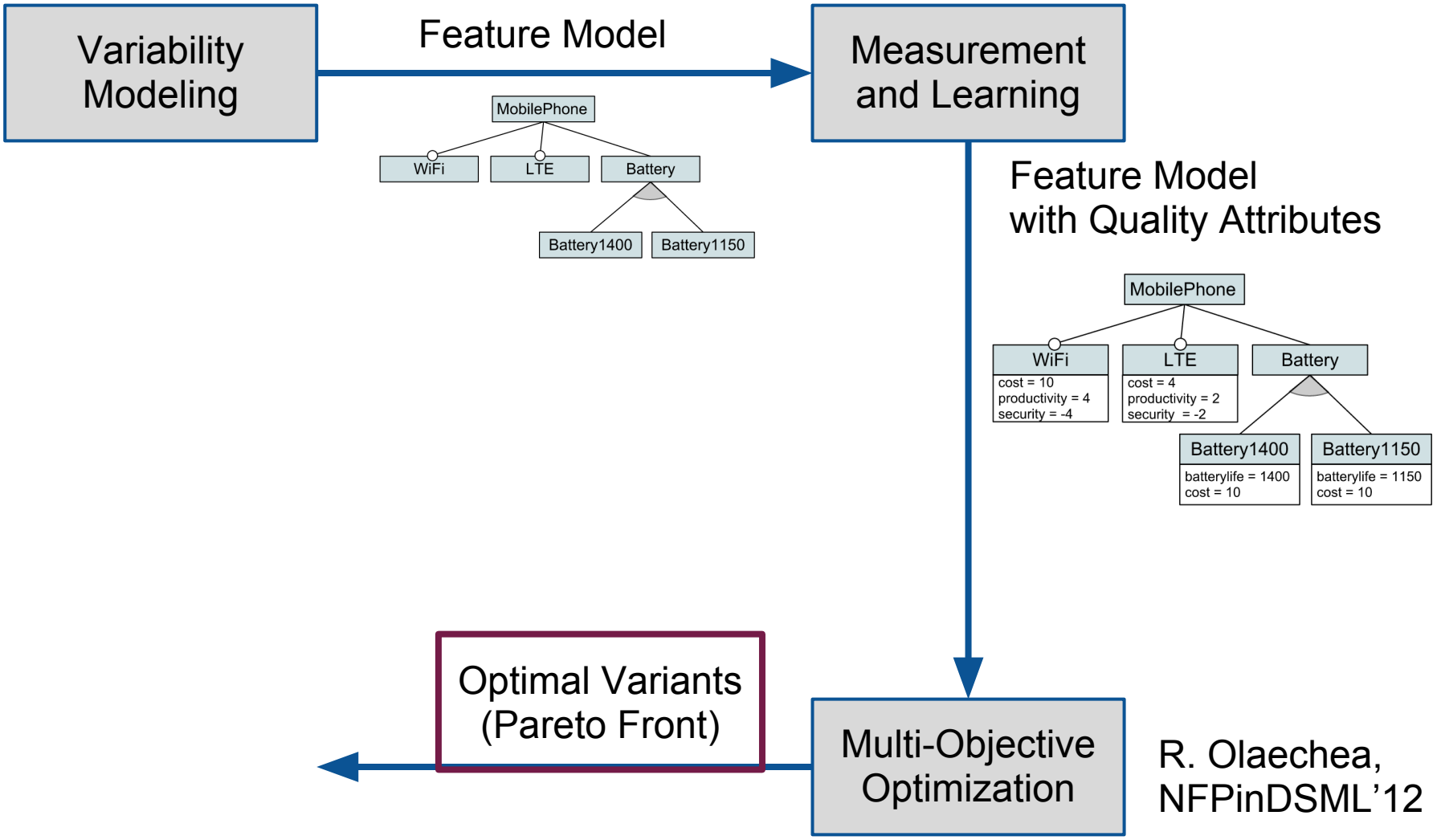
Optimization Workflow in PLE



Optimization Workflow in PLE



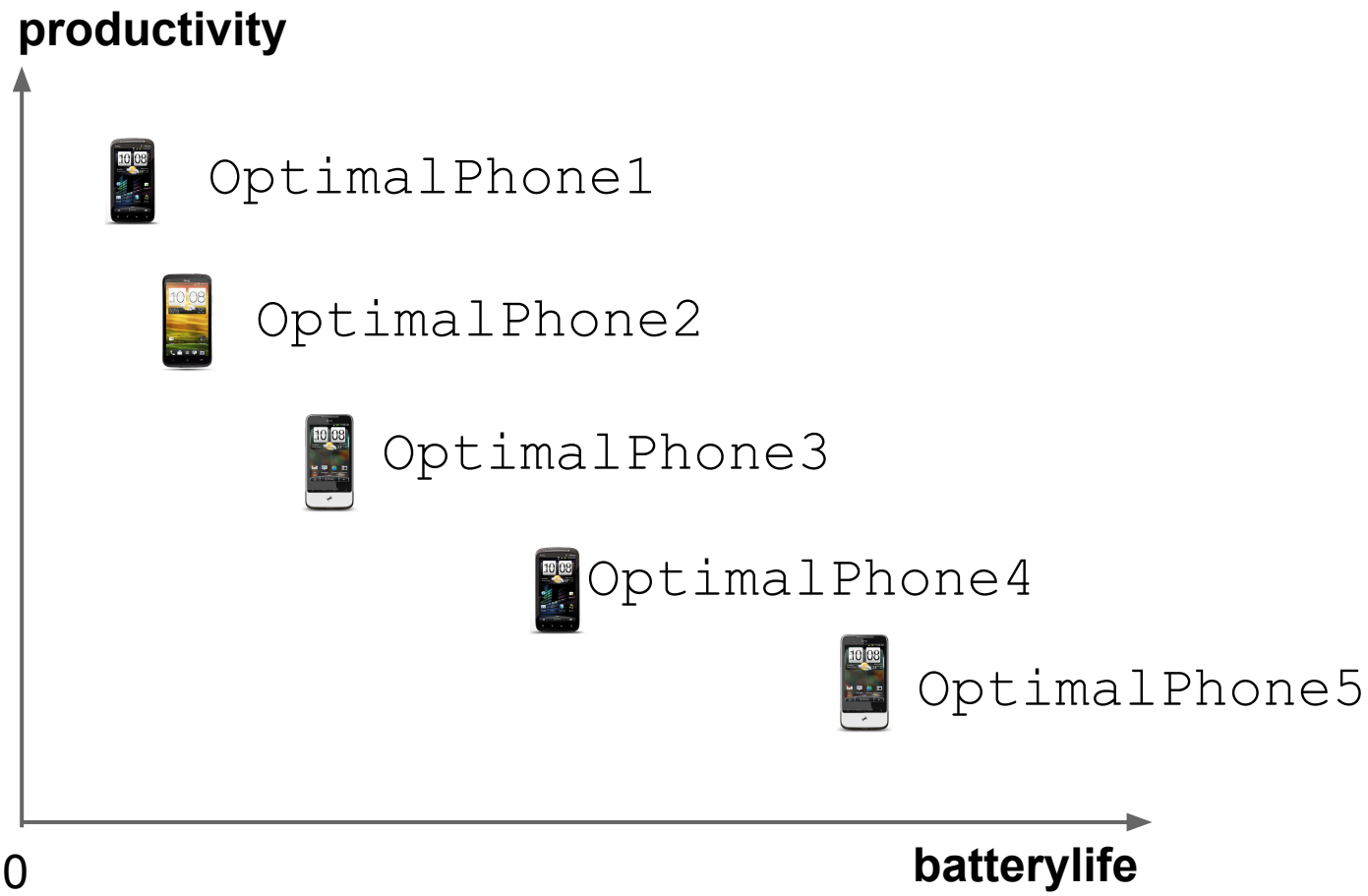
Optimization Workflow in PLE



R. Olaechea, NFPinDSML'12

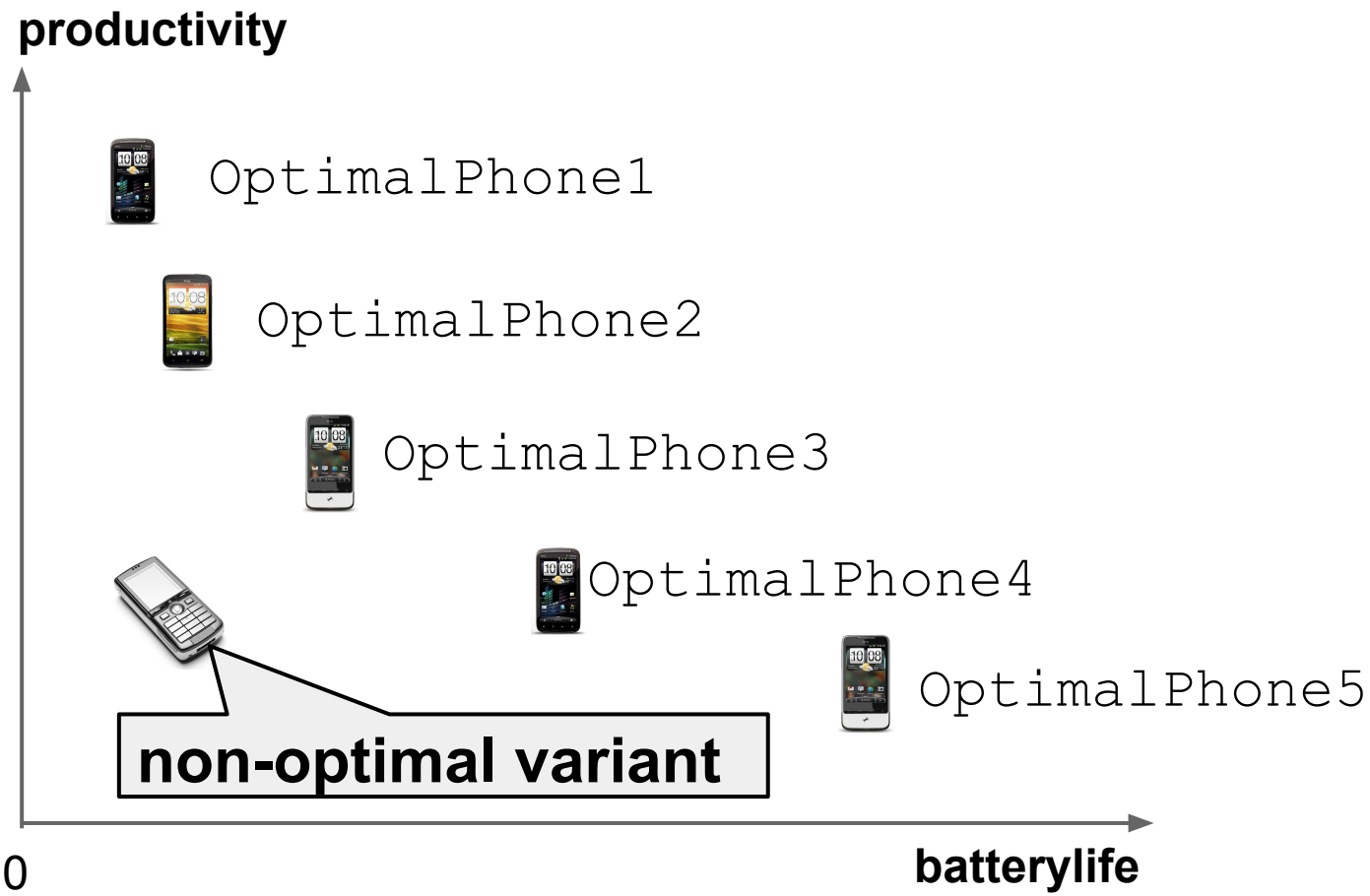
Optimal Variants (Pareto Front)

Objectives: maximize **`productivity`** and **`batterylife`**



Optimal Variants (Pareto Front)

Objectives: maximize **`productivity`** and **`batterylife`**



Non-Dominance of Optimal Variants

1. The variants are non-dominated by each other:

OptimalPhone1	OptimalPhone2	...	OptimalPhoneN
LTE	WiFi		WiFi
WiFi	Battery1150		USB
Battery1400	GSM		Battery1150
productivity = 20	**productivity = 15**		**productivity = 10**
batterylife = 10	**batterylife = 22**		**batterylife = 34**

2. Optimizers output all non-dominated optimal variants

Non-Dominance of Optimal Variants

1. The variants are non-dominated by each other:

OptimalPhone1	OptimalPhone2	...	OptimalPhoneN
LTE	WiFi		WiFi
WiFi	Battery1150		USB
Battery1400	GSM		Battery1150
productivity = 20	**productivity = 15**		**productivity = 10**
batterylife = 10	**batterylife = 22**		**batterylife = 34**

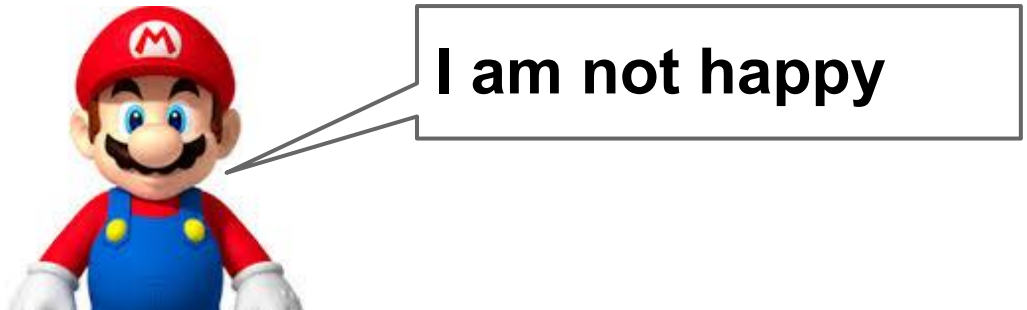
2. Optimizers output all non-dominated optimal variants

Non-Dominance of Optimal Variants

1. The variants are non-dominated by each other:

OptimalPhone1	OptimalPhone2	...	OptimalPhoneN
LTE	WiFi		WiFi
WiFi	Battery1150		USB
Battery1400	GSM		Battery1150
productivity = 20	**productivity = 15**		**productivity = 10**
batterylife = 10	**batterylife = 22**		**batterylife = 34**

2. Optimizers output all non-dominated optimal variants



Non-Dominance of Optimal Variants

1. The variants are non-dominated by each other:

OptimalPhone1	OptimalPhone2	...	OptimalPhoneN
LTE	WiFi		WiFi
WiFi	Battery1150		USB
Battery1400	GSM		Battery1150
productivity = 20	**productivity = 15**		**productivity = 10**
batterylife = 10	**batterylife = 22**		**batterylife = 34**

2. Optimizers output all non-dominated optimal variants

I need only <u>some</u> optimal variants. How do I get them?

Use Cases (1)

1.1 See quality **ranges**: min and max `batterylife`?

1.2 **Sort** variants by `productivity`?

1.3 See **correlation**: `security ~ cost`?

1.4 See **distribution**: most variants are at which `cost`?

1.5 Get variants **by quality:** with `cost ≥ $125`?

Use Cases (2)

2.1 See feature **occurrences**: is `USB` frequent or rare?

2.2 Get variants **by features**: with `WiFi`, without `LTE`?

2.3 See **cumulative impact** on quality: `USB + LTE`?

2.4 Choose **desired** variants by features and quality?

Use Cases (3)

3.1 Explore variants **individually**?

3.2 Select variants with a **similar** features?

3.3 Observe **evolution** of optimal variants?

Problem Statement

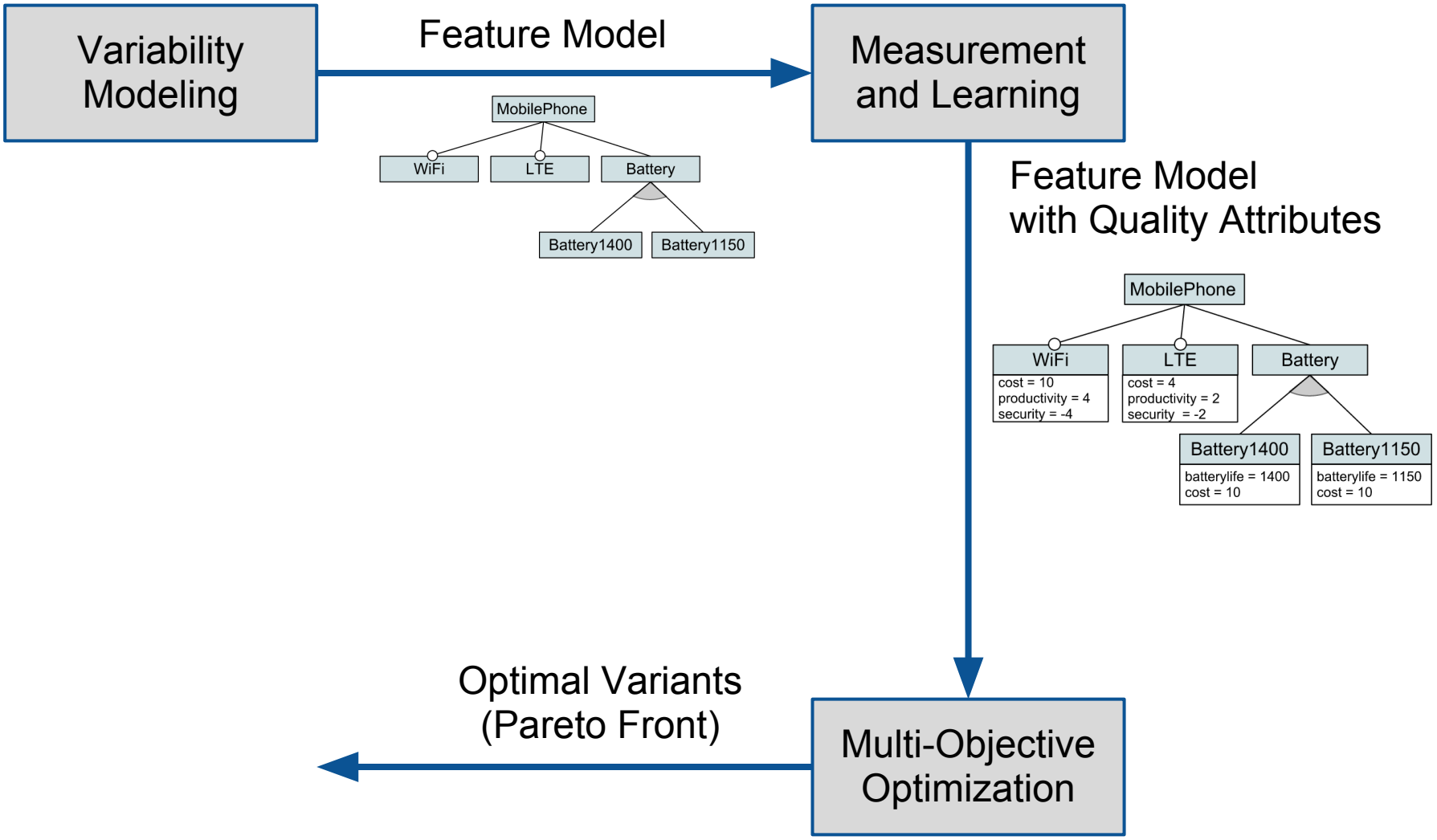
Product line engineers need:

- A global view onto a Pareto Front - **Visualization**
- To perform tasks with a Pareto Front - **Exploration**

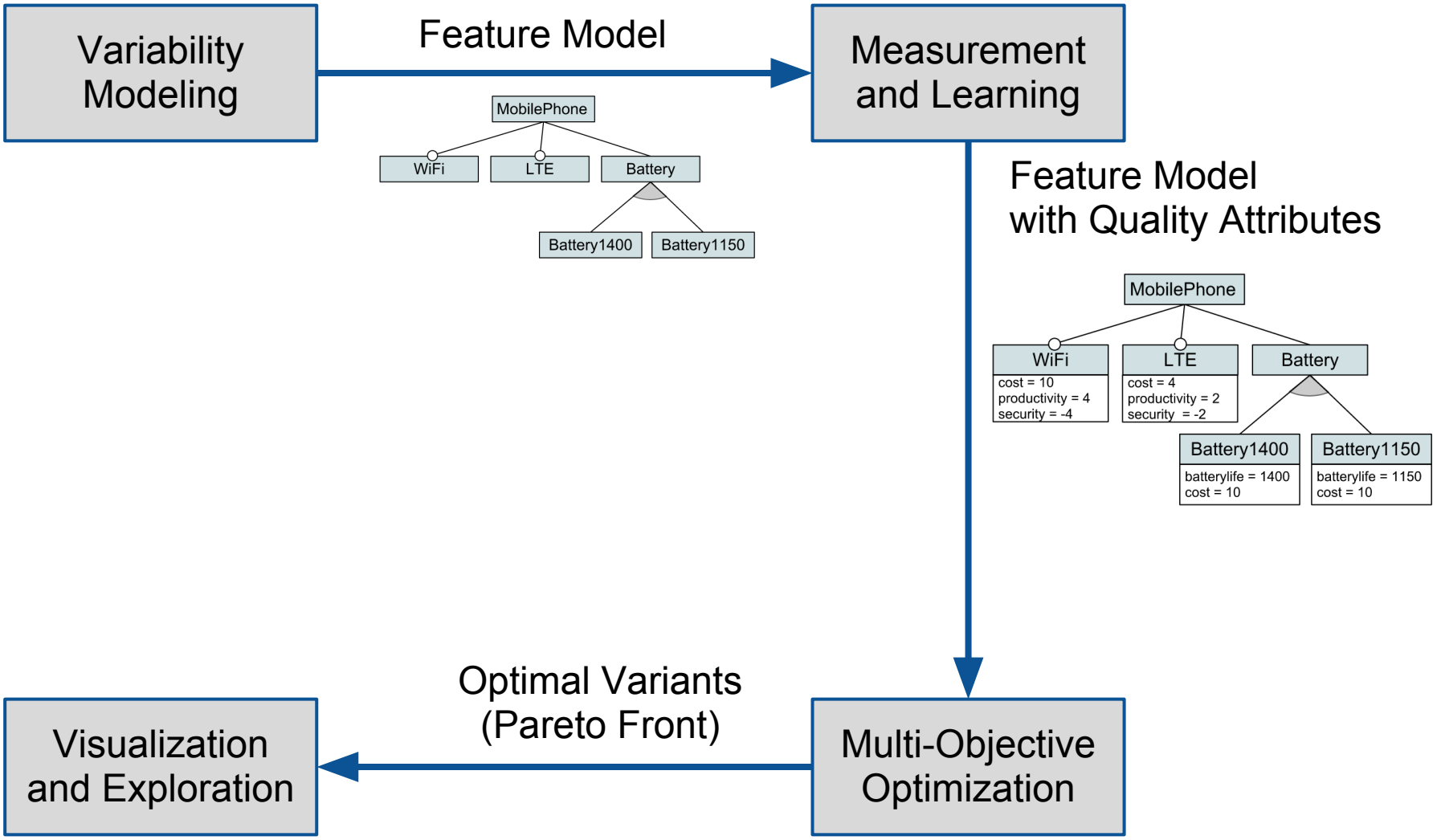
We propose:

- A tool for **visualization and exploration**

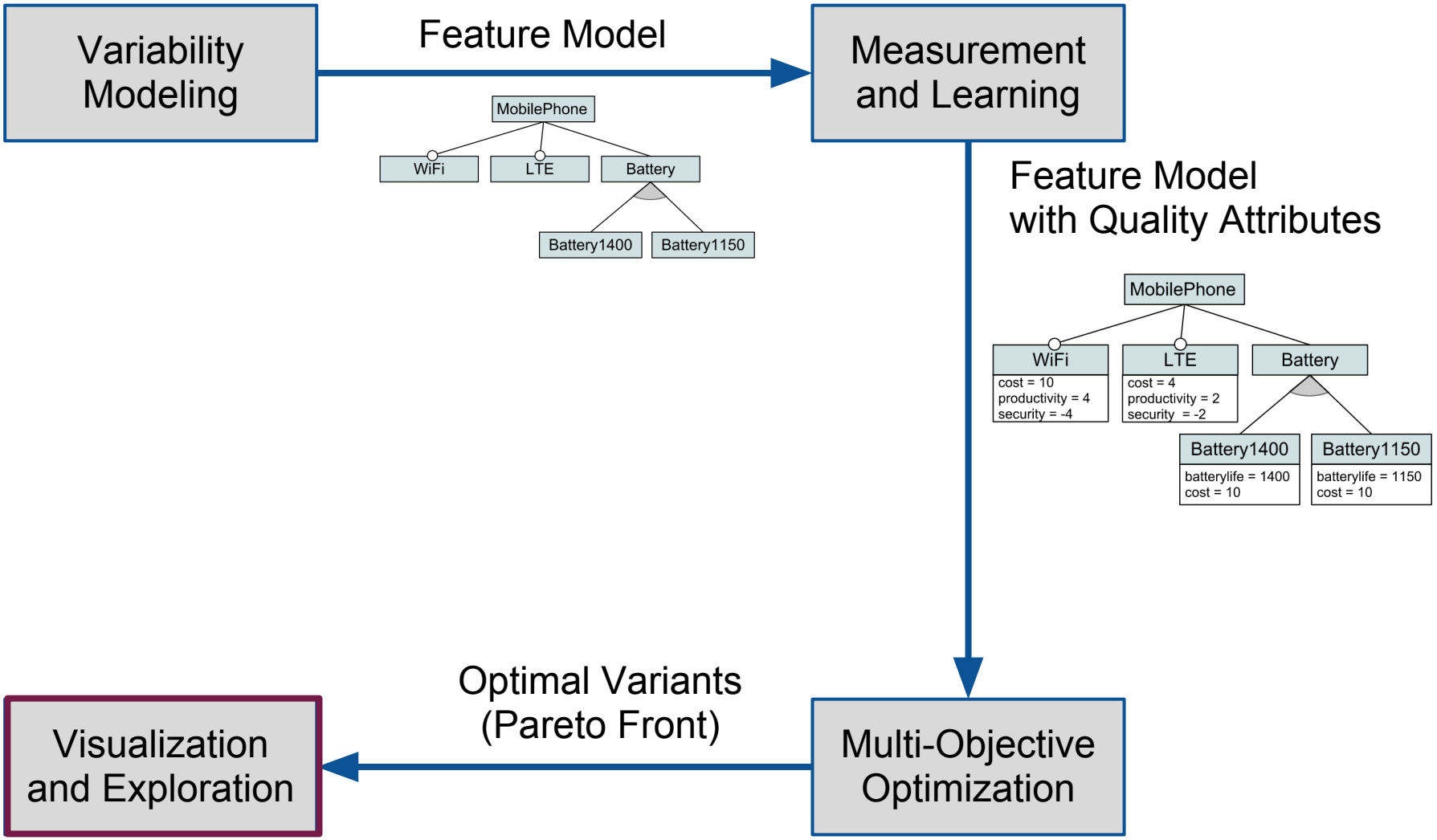
Optimization Workflow in PLE



Optimization Workflow in PLE



Optimization Workflow in PLE

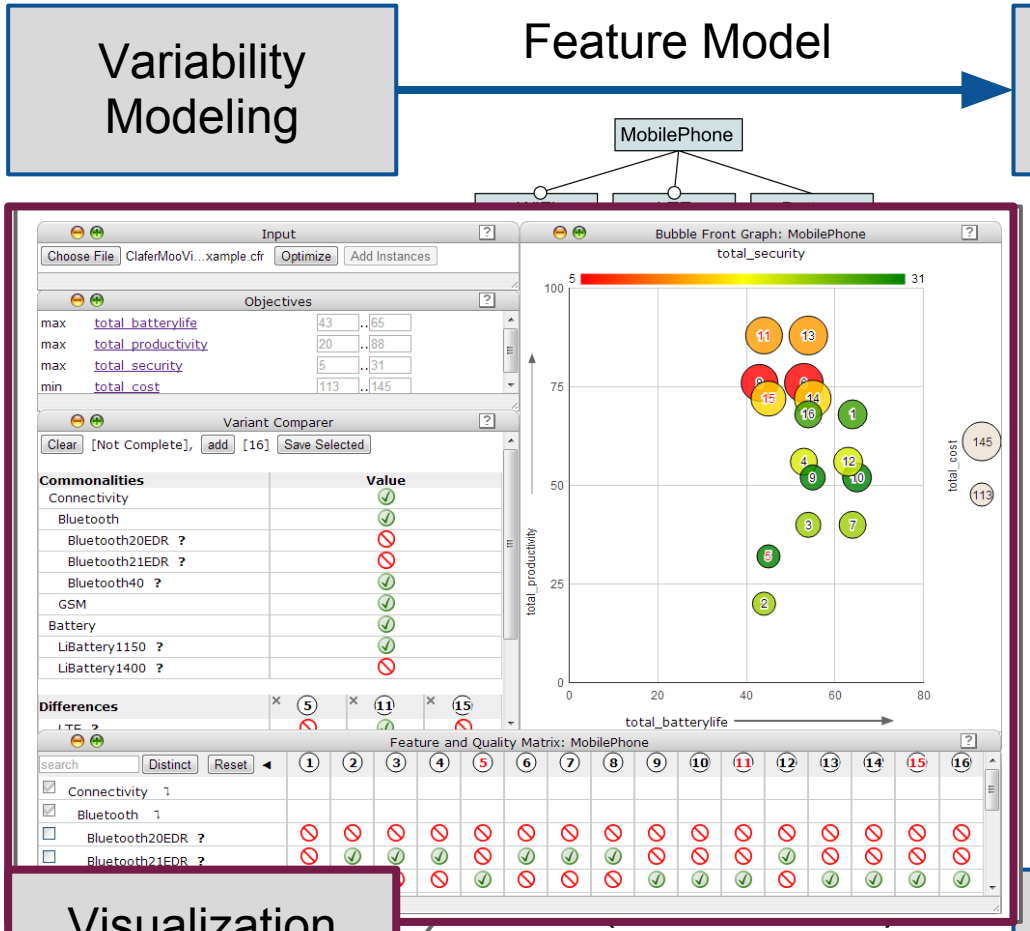


Optimization Workflow in PLE

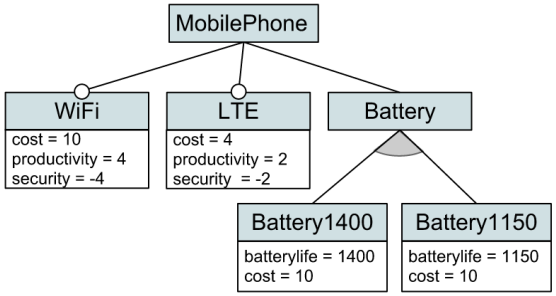
Variability Modeling

Feature Model

Measurement and Learning



Feature Model with Quality Attributes



Visualization and Exploration

Multi-Objective Optimization

Use Cases (1)

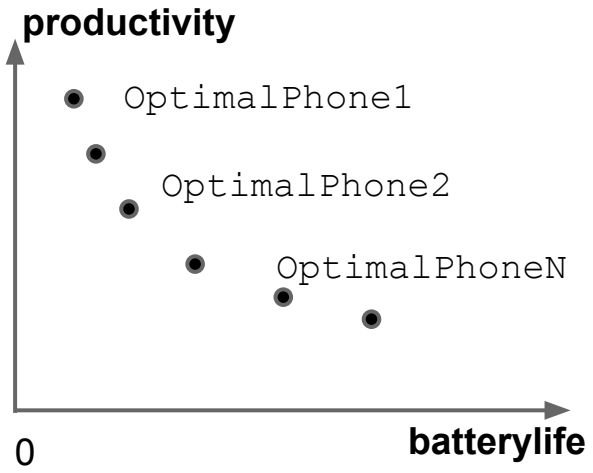
1.1 See quality **ranges**: min and max `batterylife`?

1.2 **Sort** variants by `productivity`?

1.3 See **correlation**: `security ~ cost`?

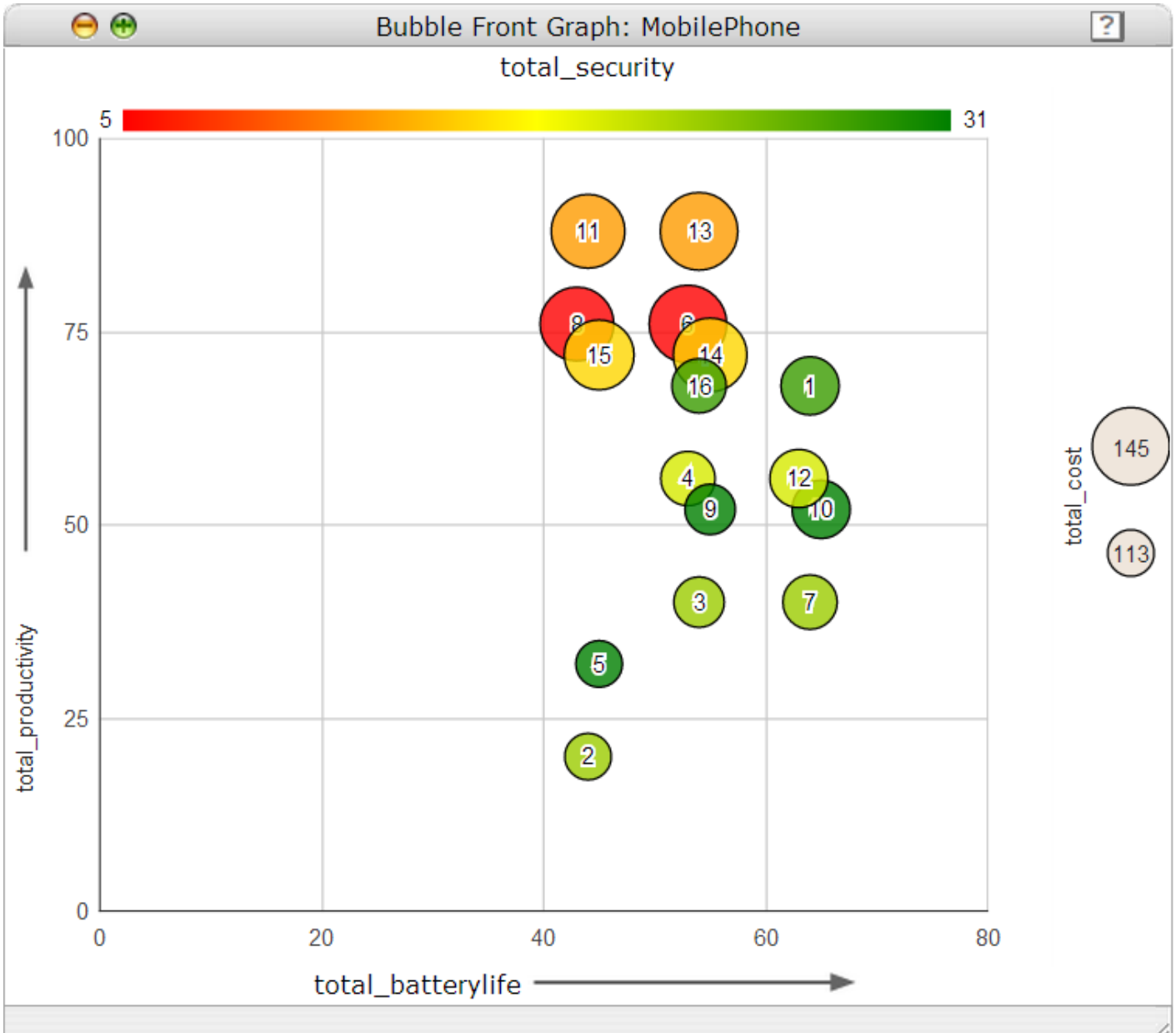
1.4 See **distribution**: most variants are at which `cost`?

1.5 Get variants **by quality:** with `cost ≥ $125`?

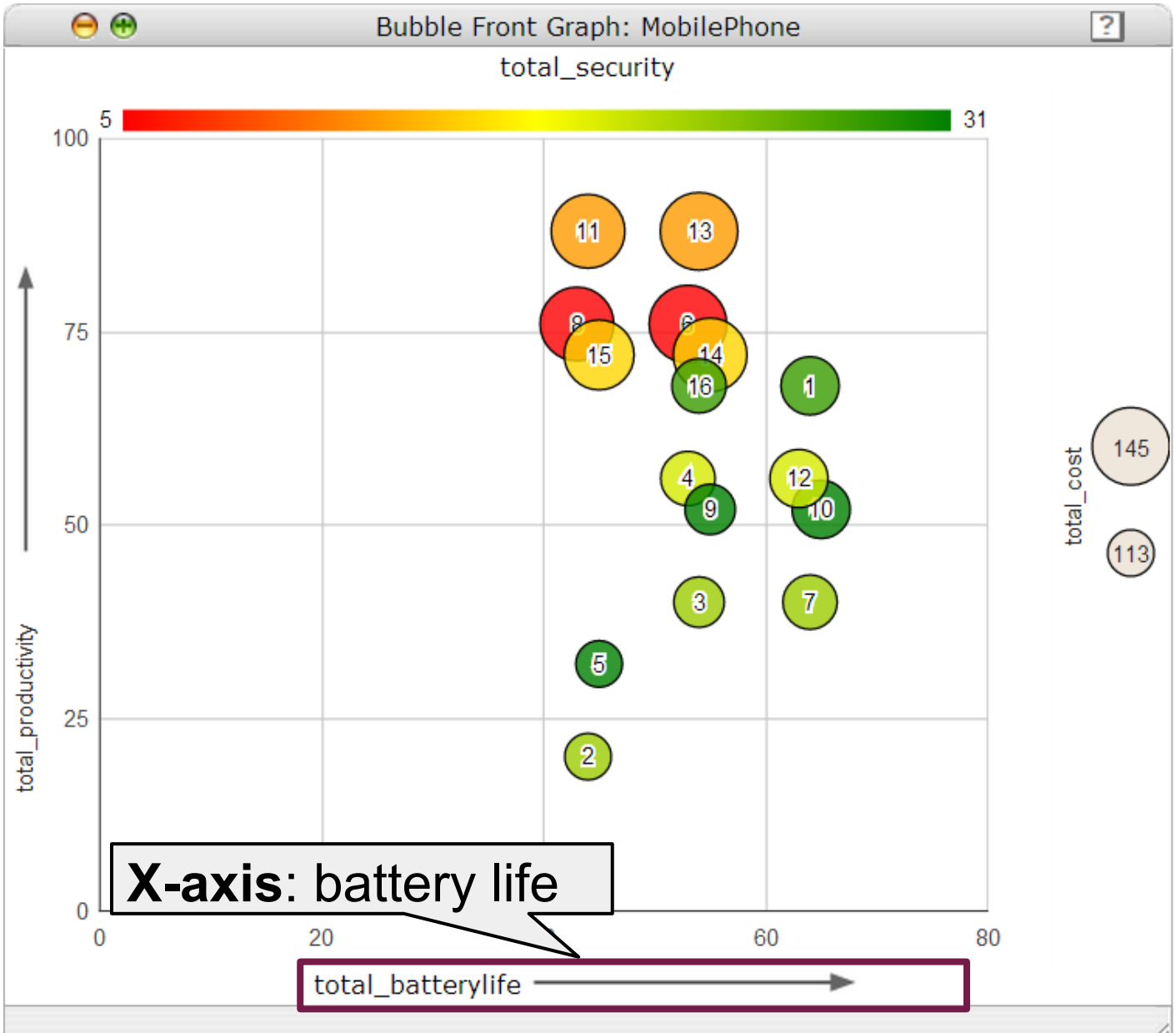



```
OptimalPhone1          ...   OptimalPhoneN
  LTE                          WiFi
  WiFi                         USB
  Battery1400                  Battery1150
  productivity = 20            productivity = 18
  batterylife = 10             batterylife = 9
```

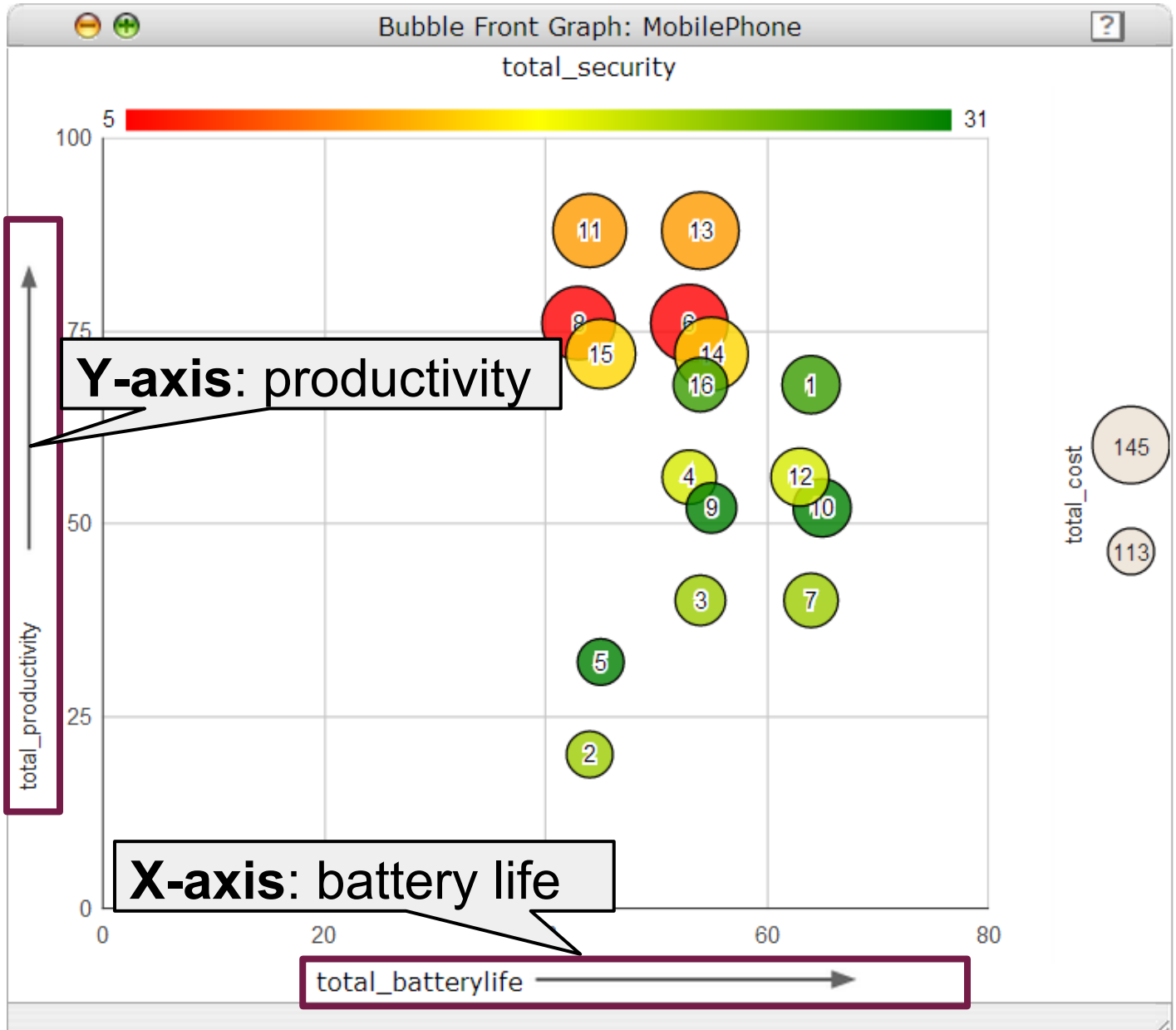
Bubble Front Graph



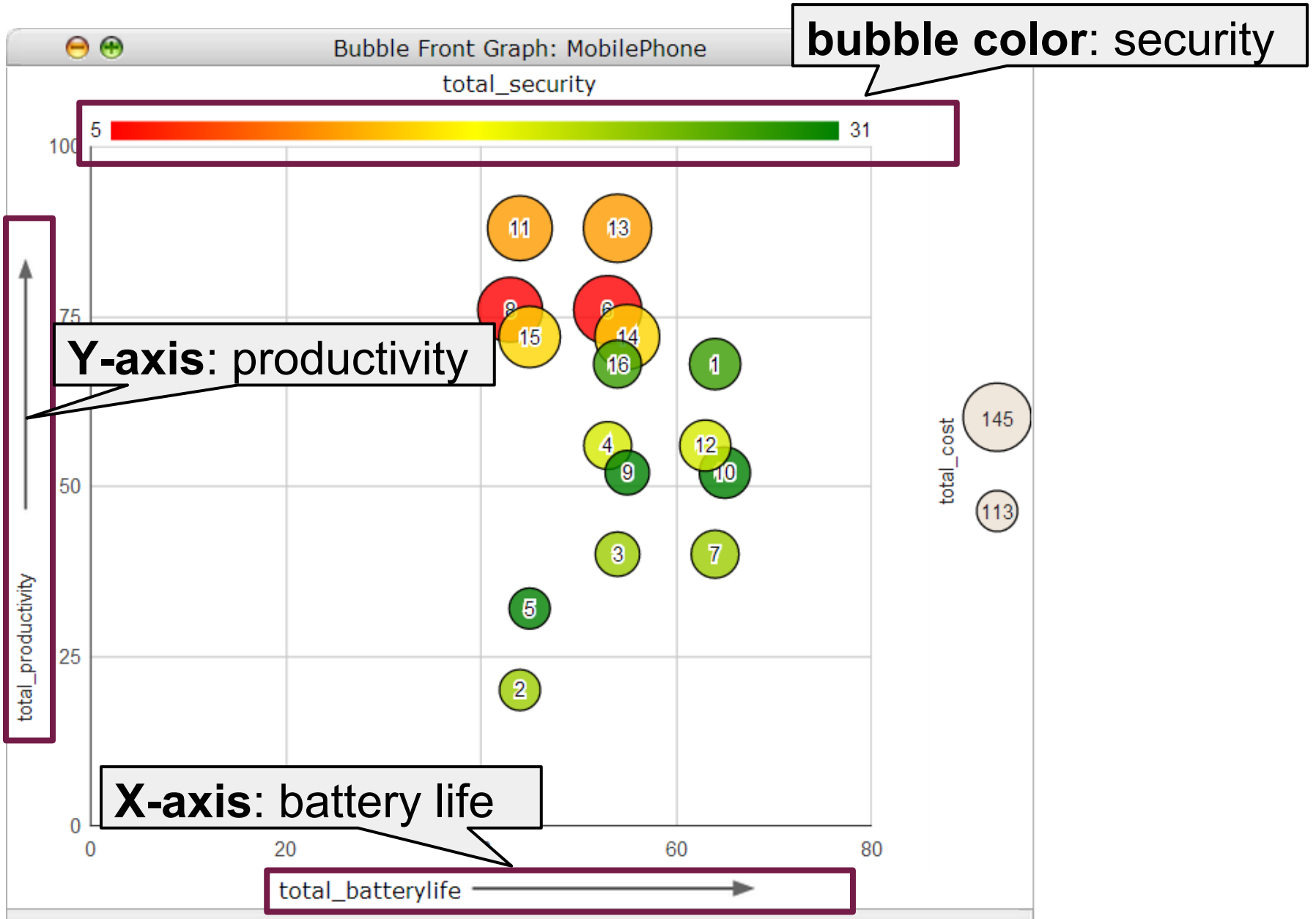
Bubble Front Graph



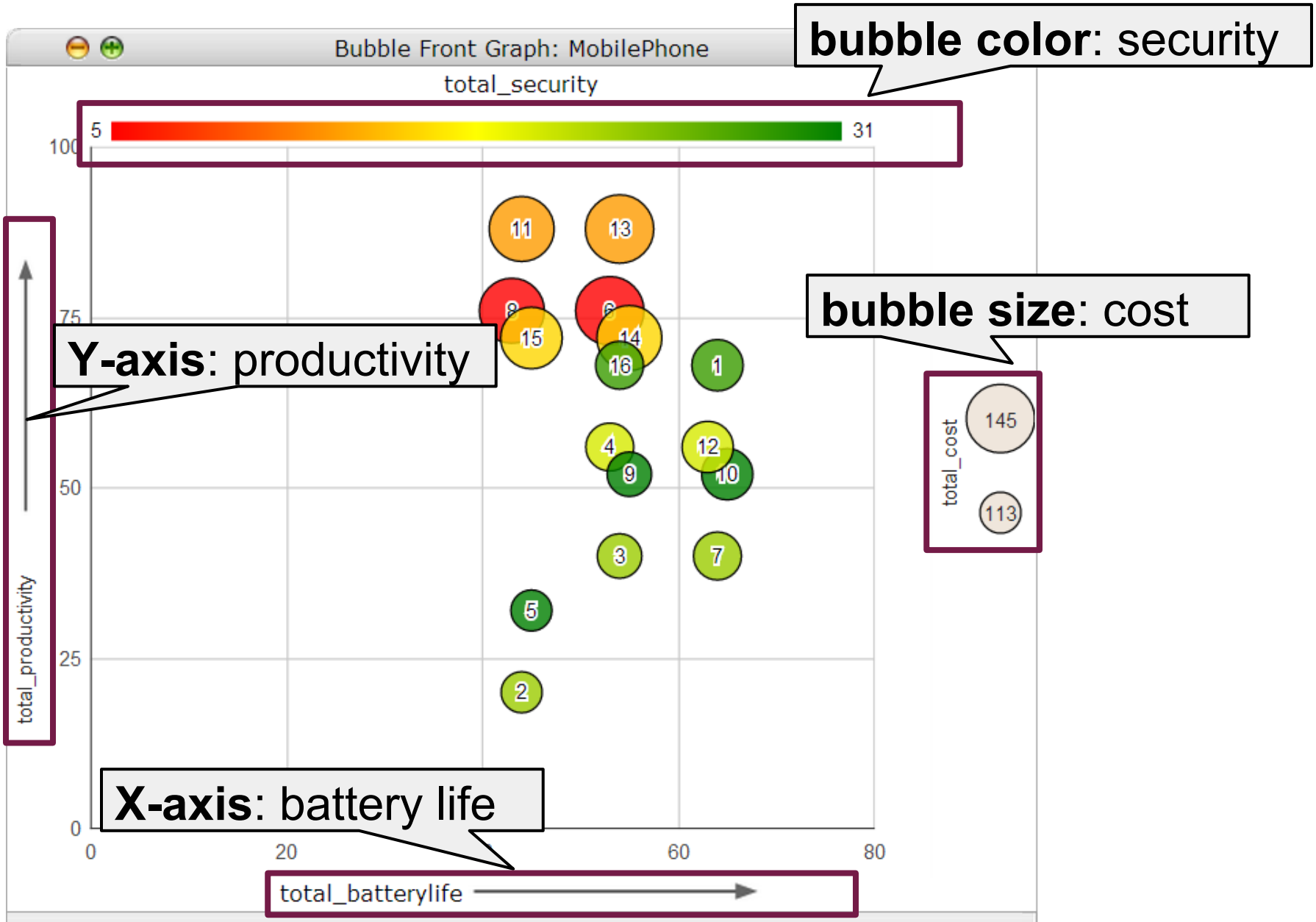
Bubble Front Graph



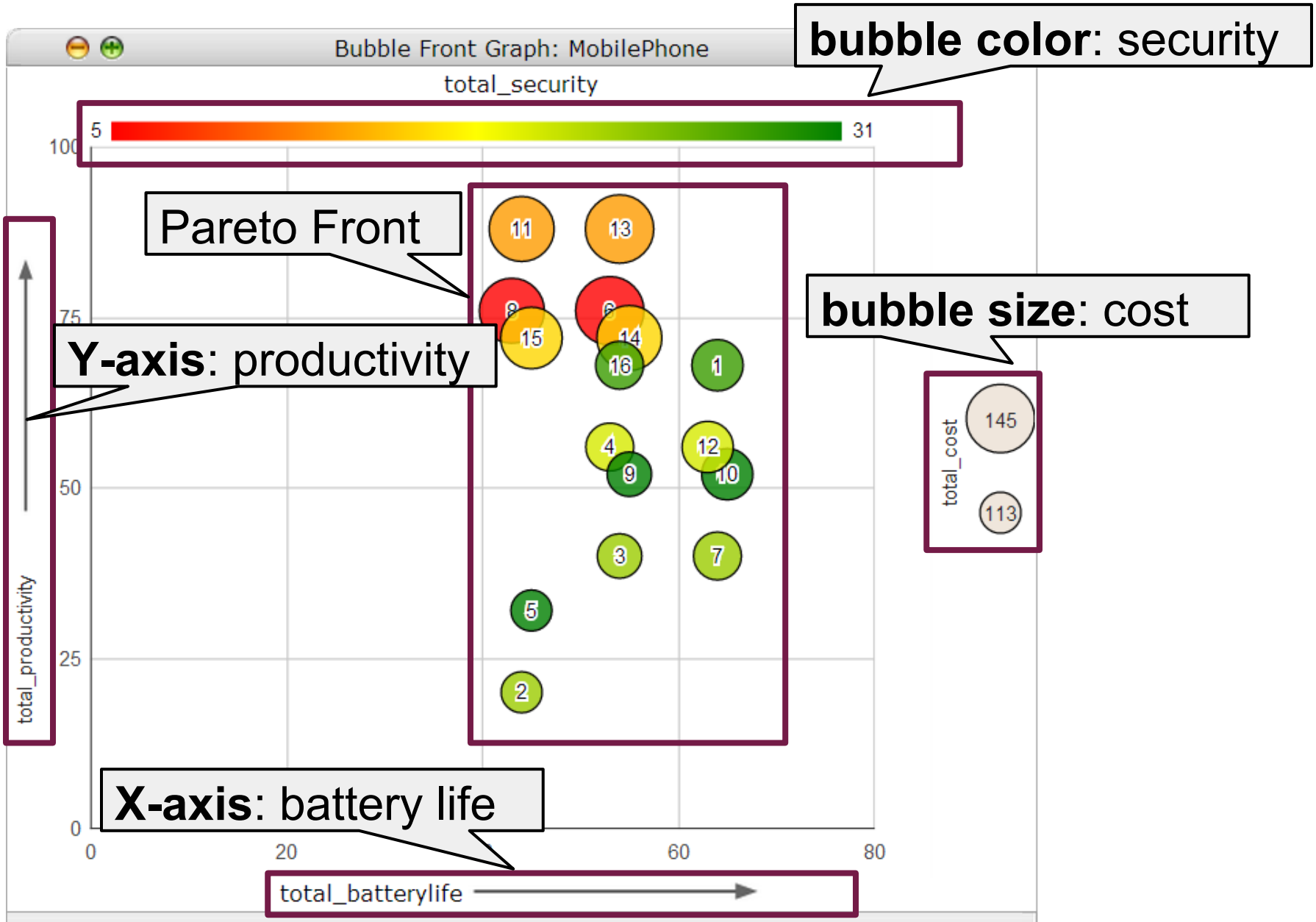
Bubble Front Graph



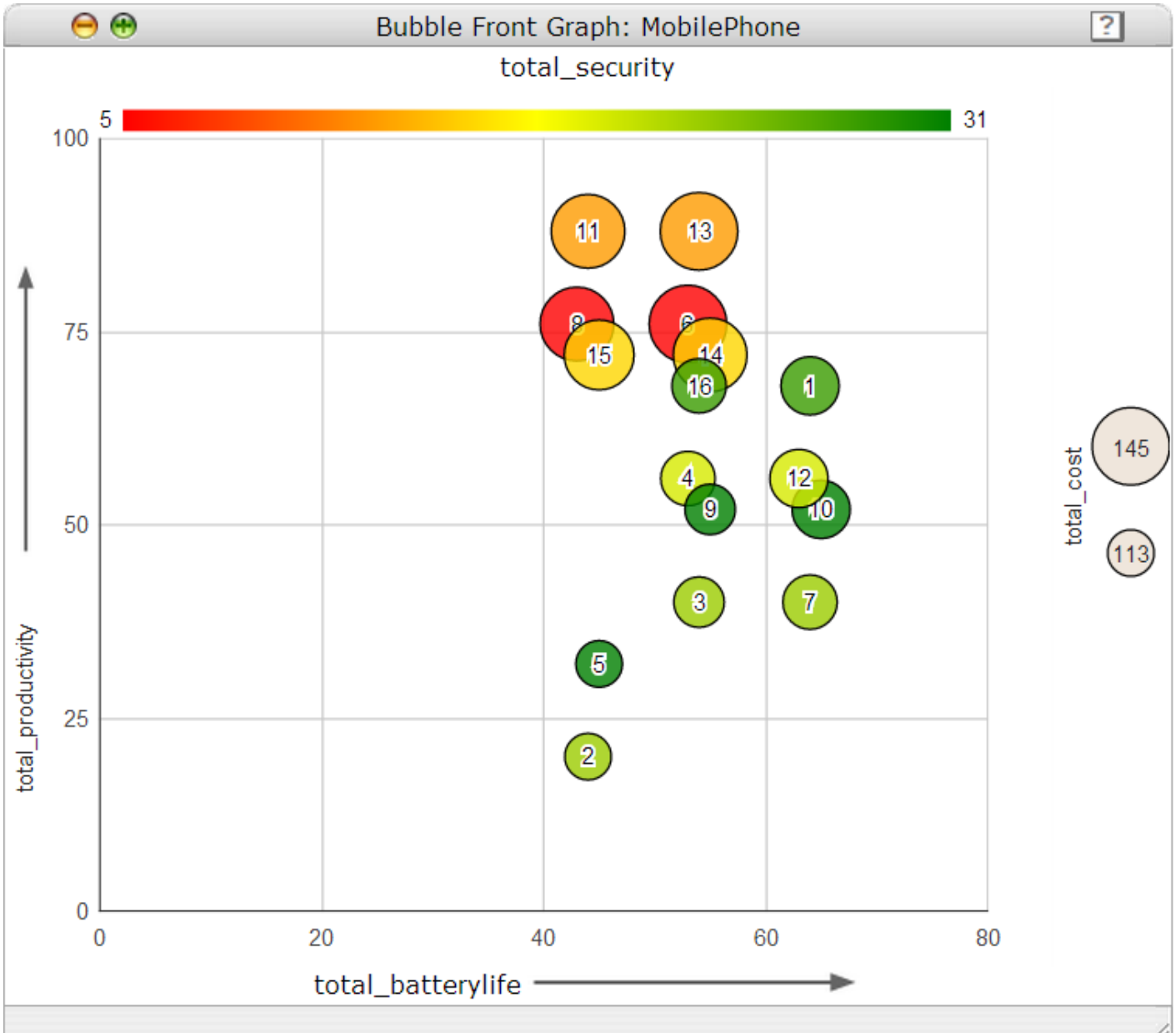
Bubble Front Graph



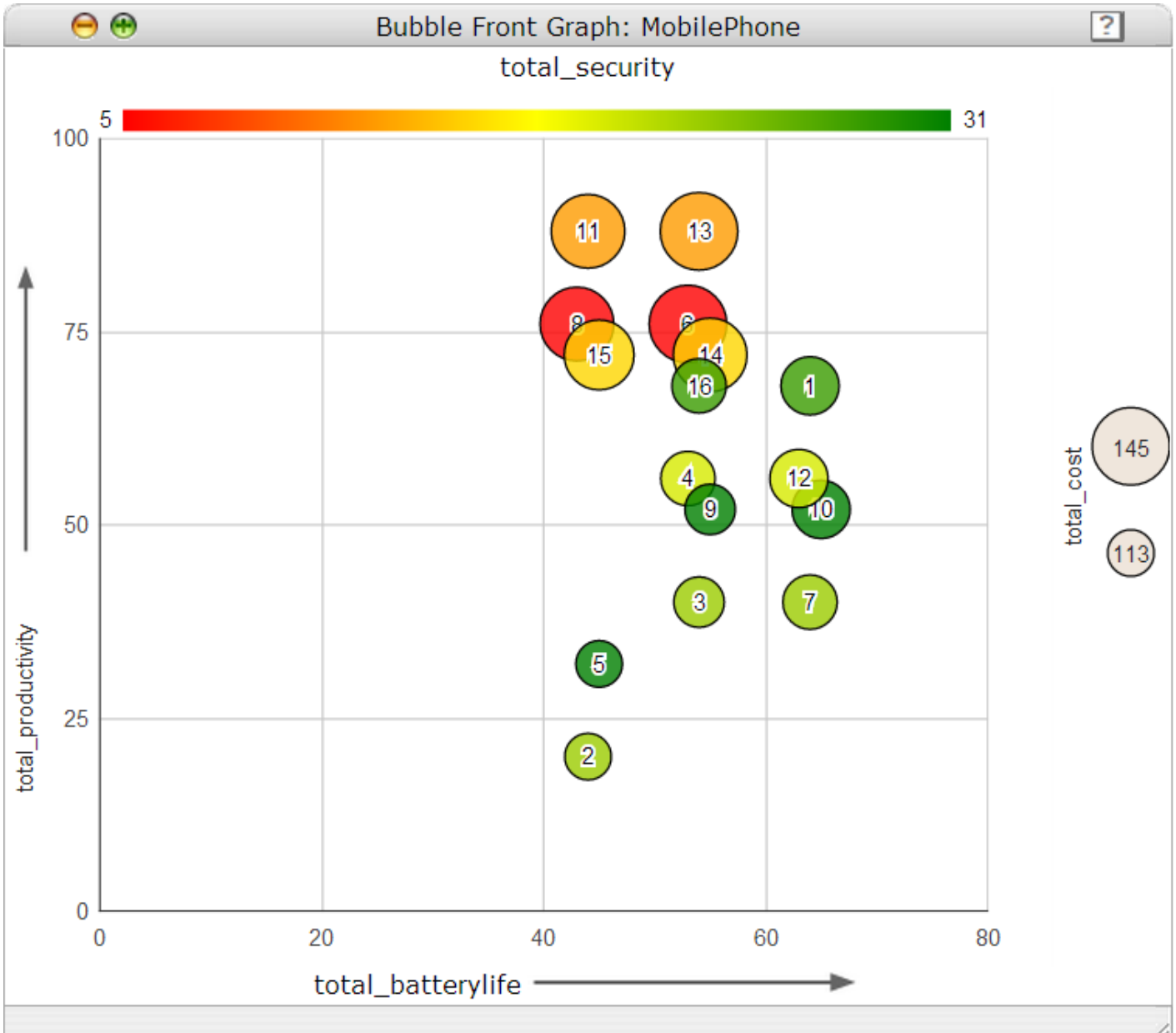
Bubble Front Graph



Bubble Front Graph

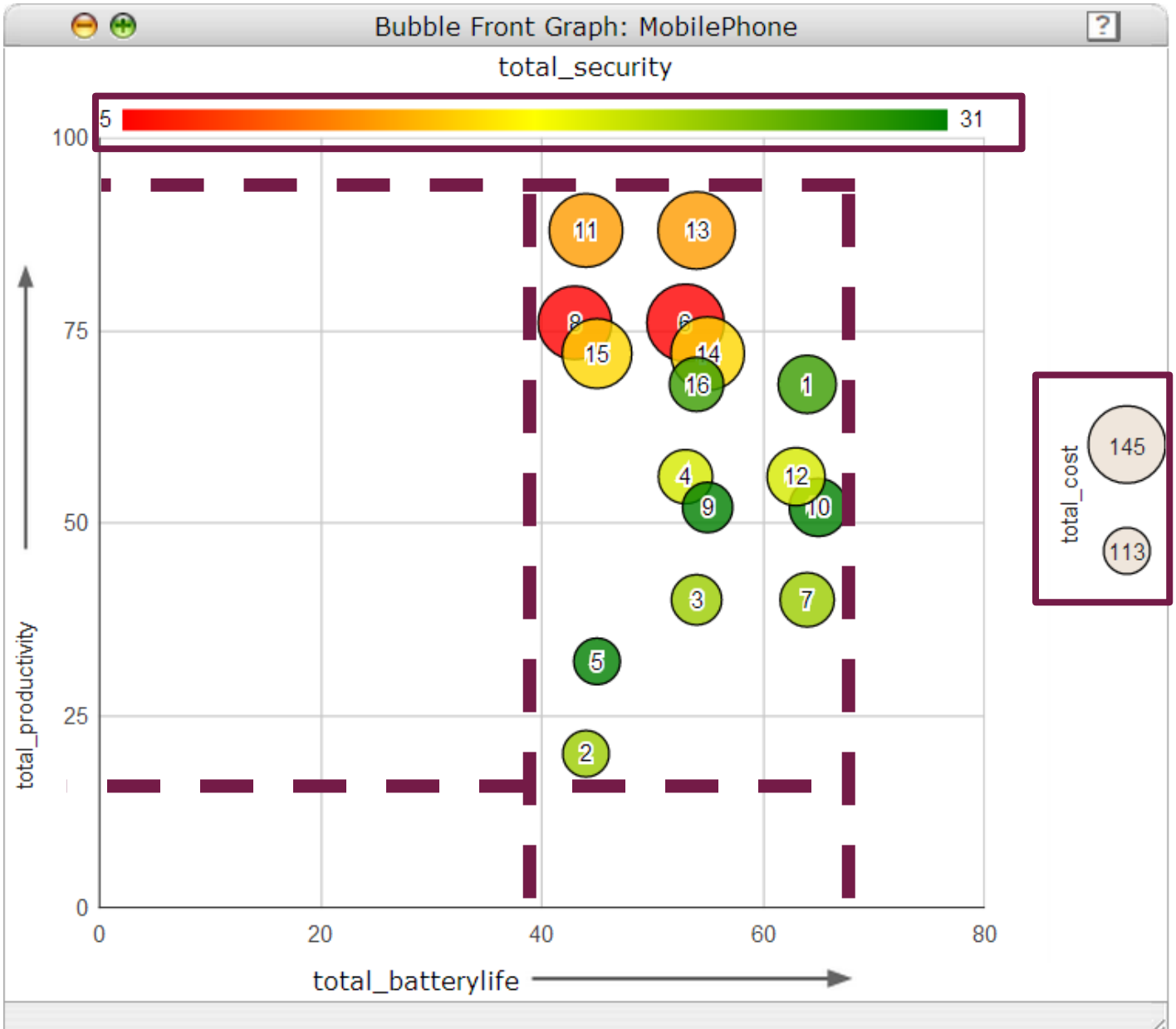


1.1 See Quality Ranges

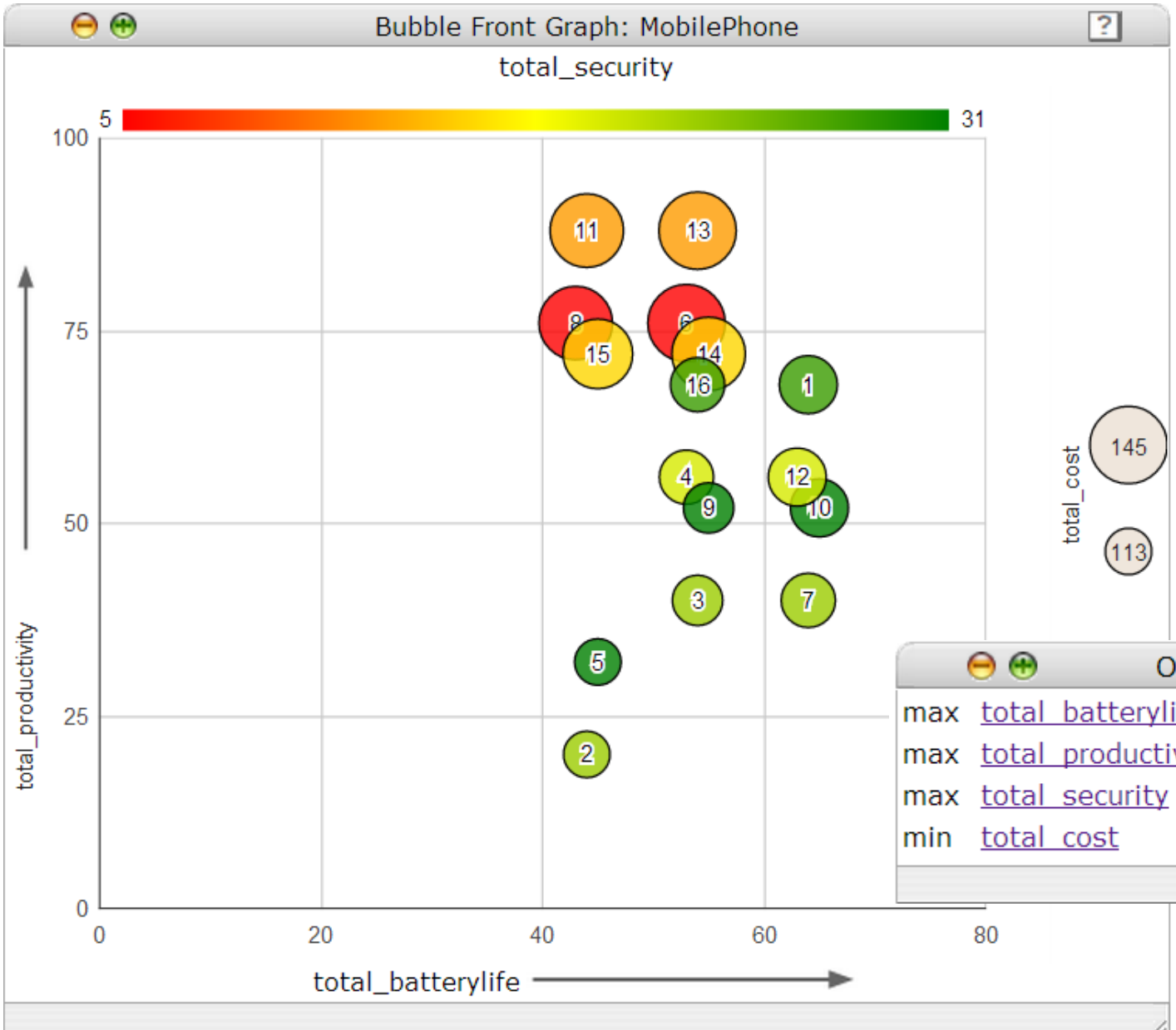


1.1 See Quality Ranges

1.1 See Quality Ranges



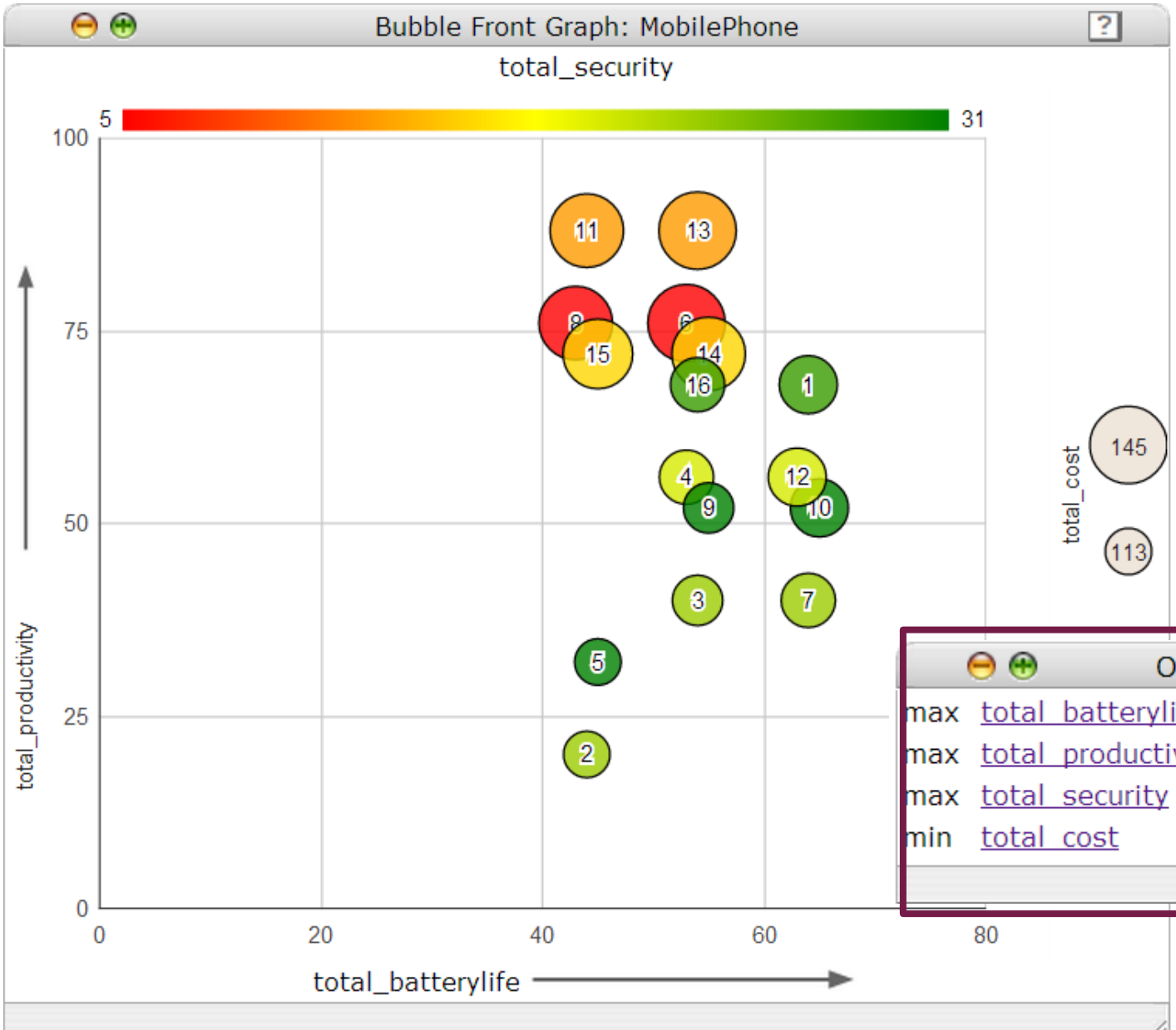
1.1 See Quality Ranges

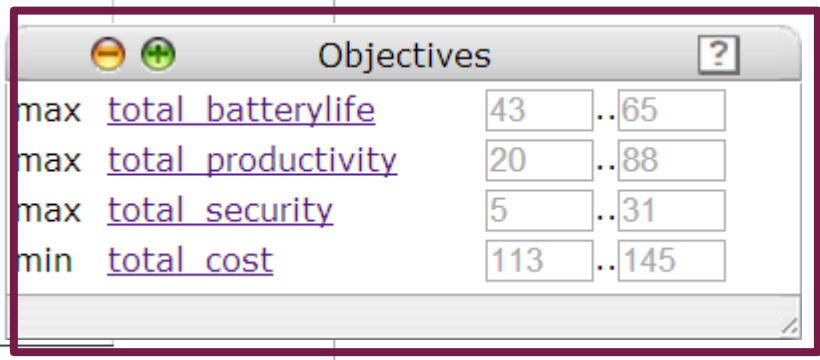


Objectives

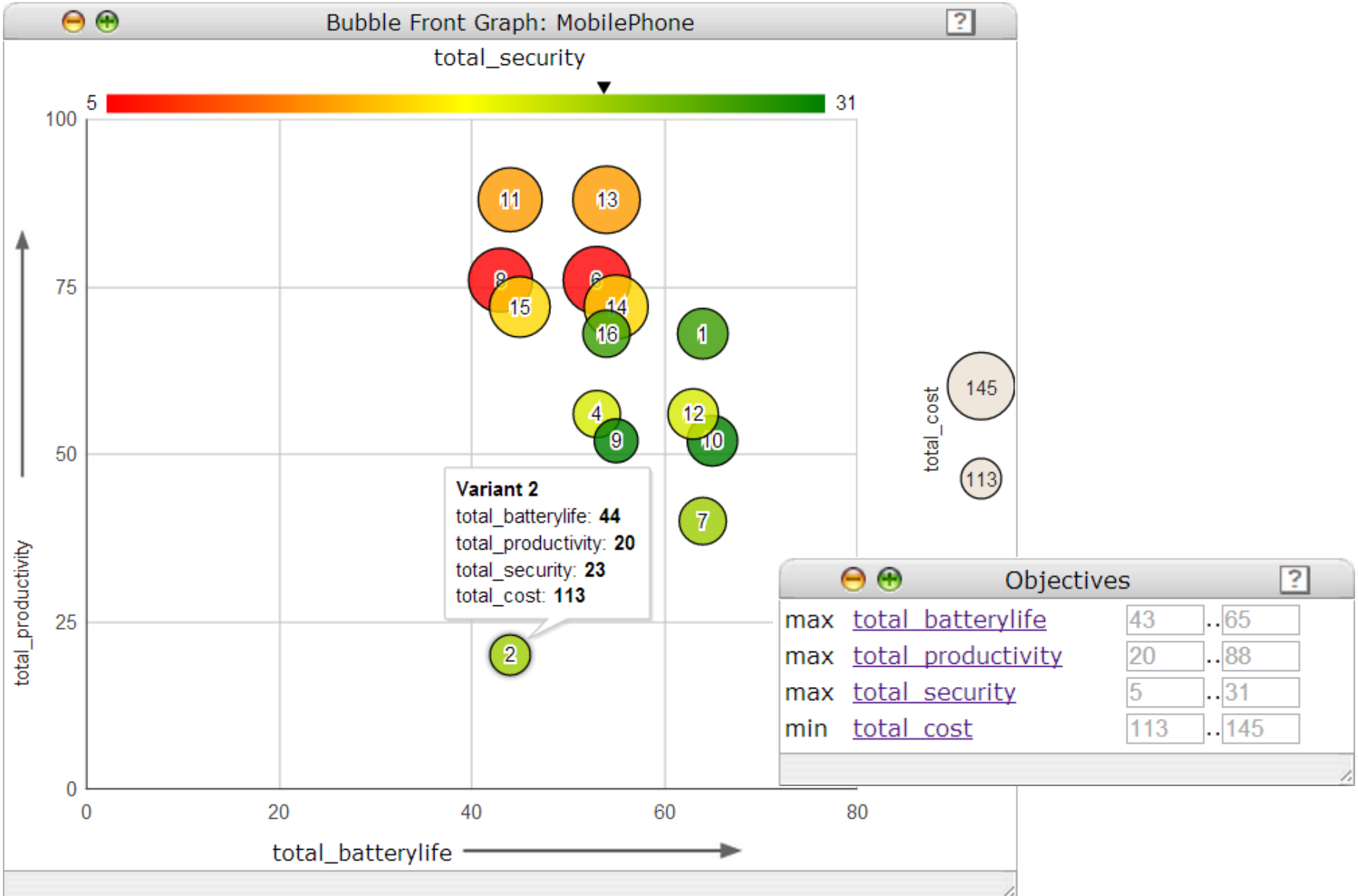
max	total_batterylife	43 ..	65
max	total_productivity	20 ..	88
max	total_security	5 ..	31
min	total_cost	113 ..	145

1.1 See Quality Ranges

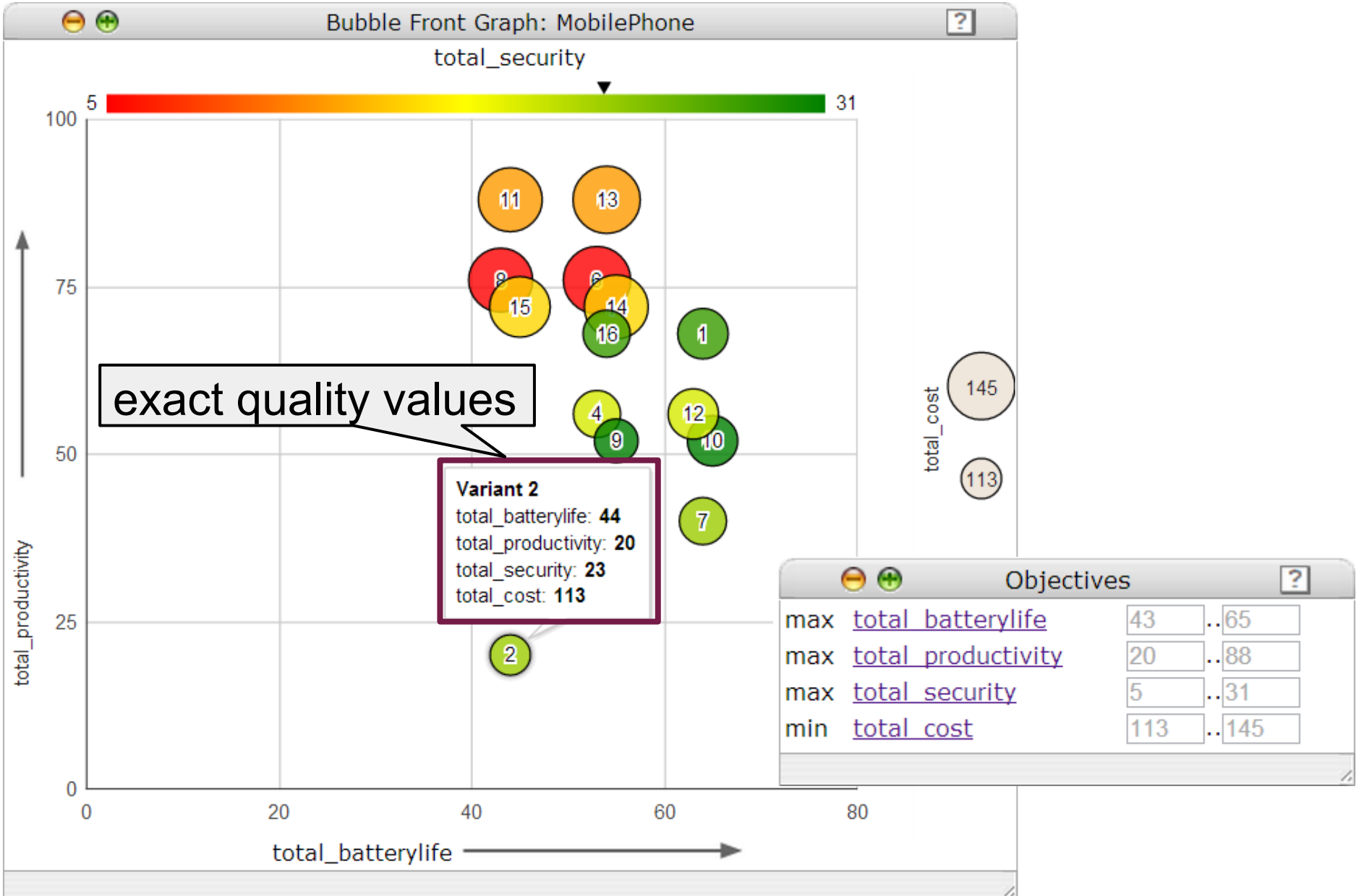




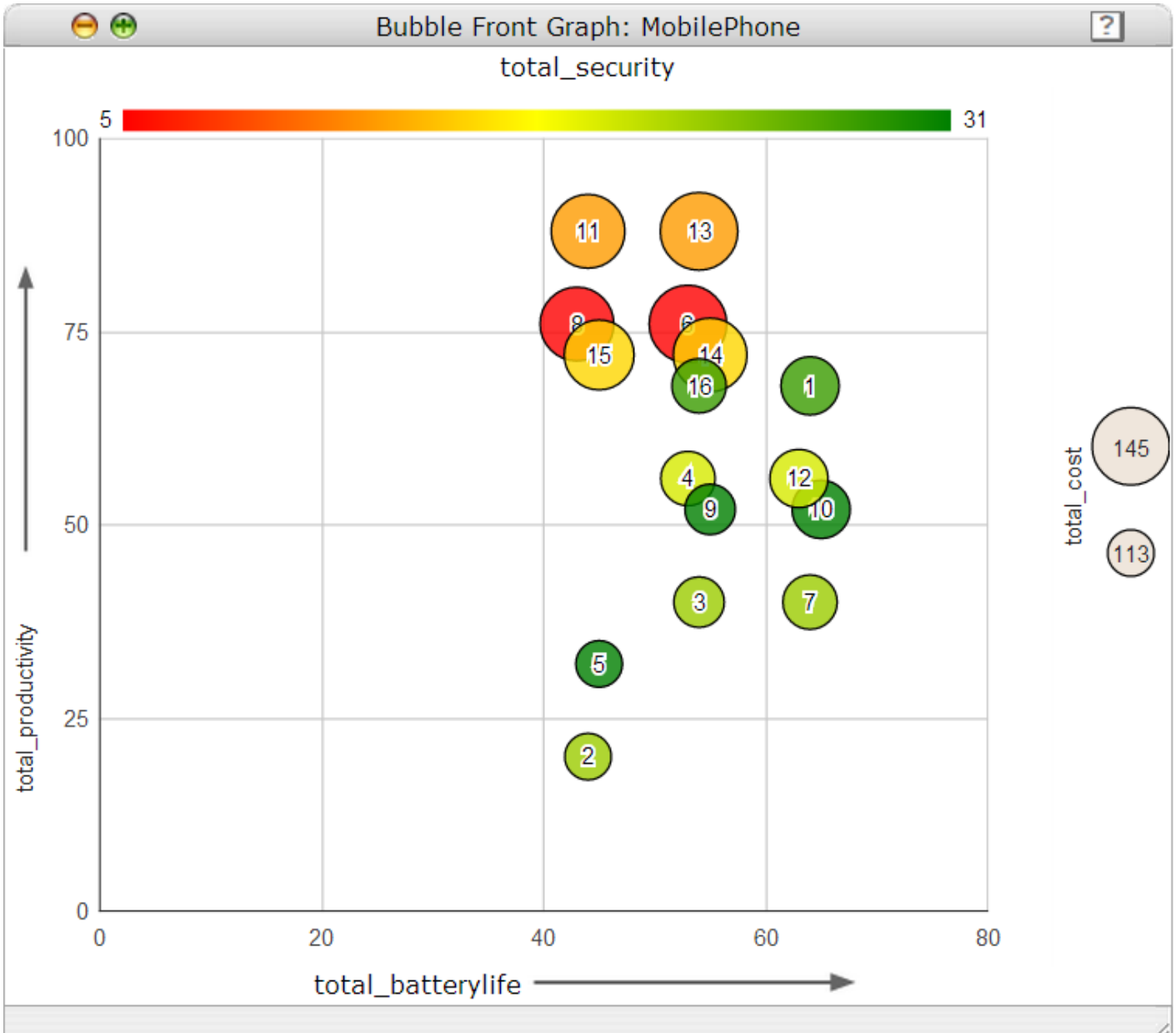
1.1 See Quality Ranges



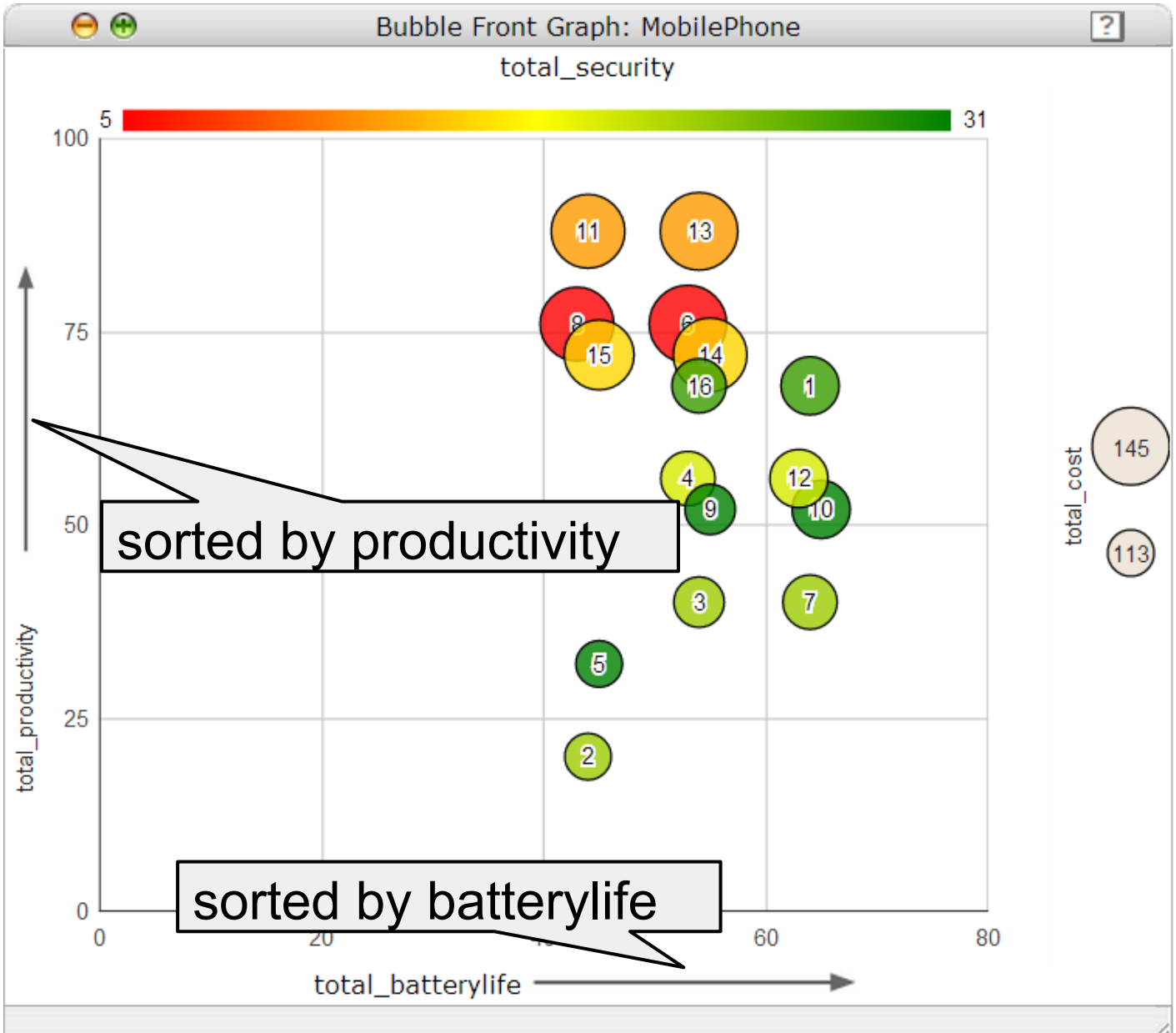
1.1 See Quality Ranges



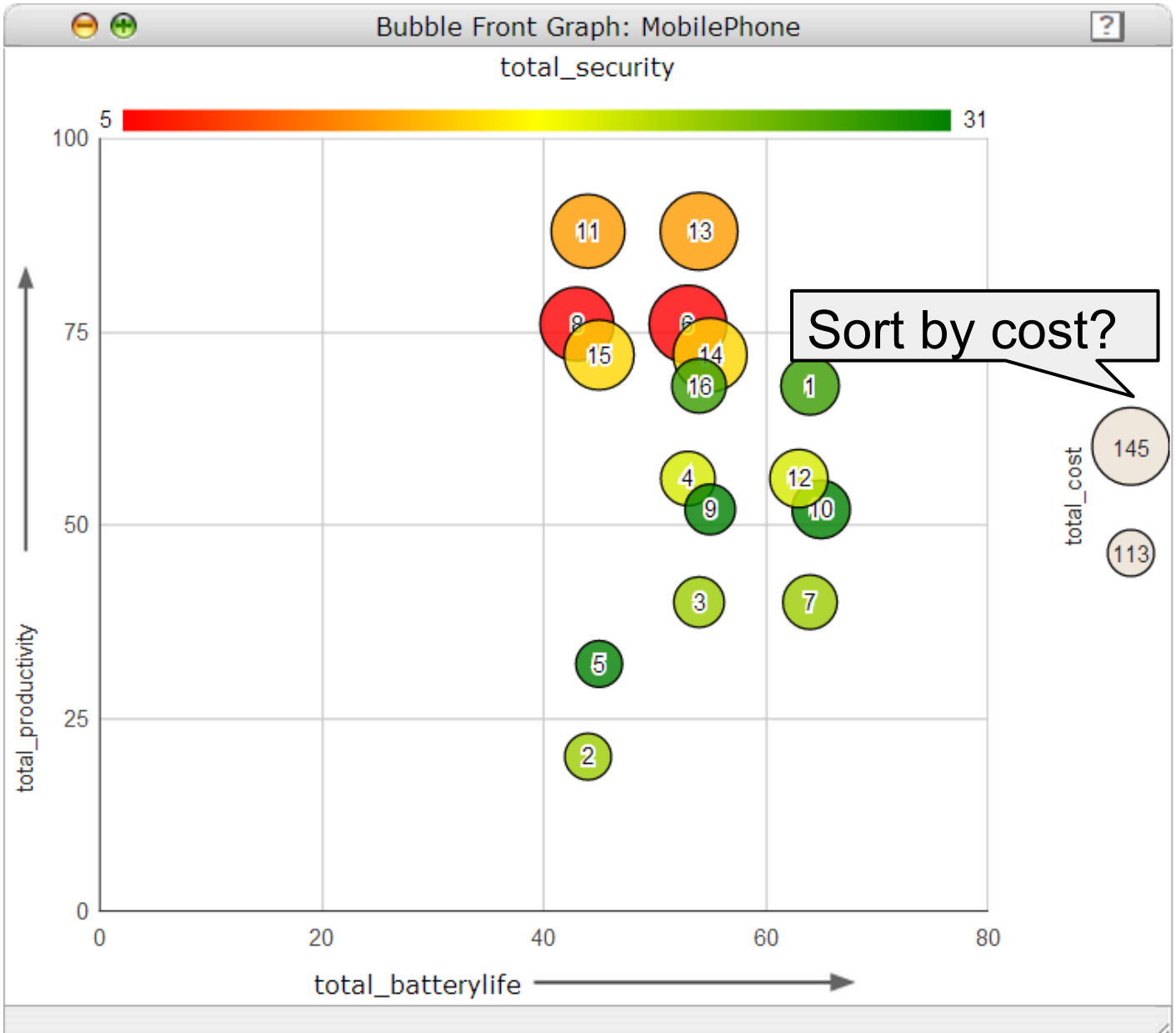
1.2 Sort by Quality



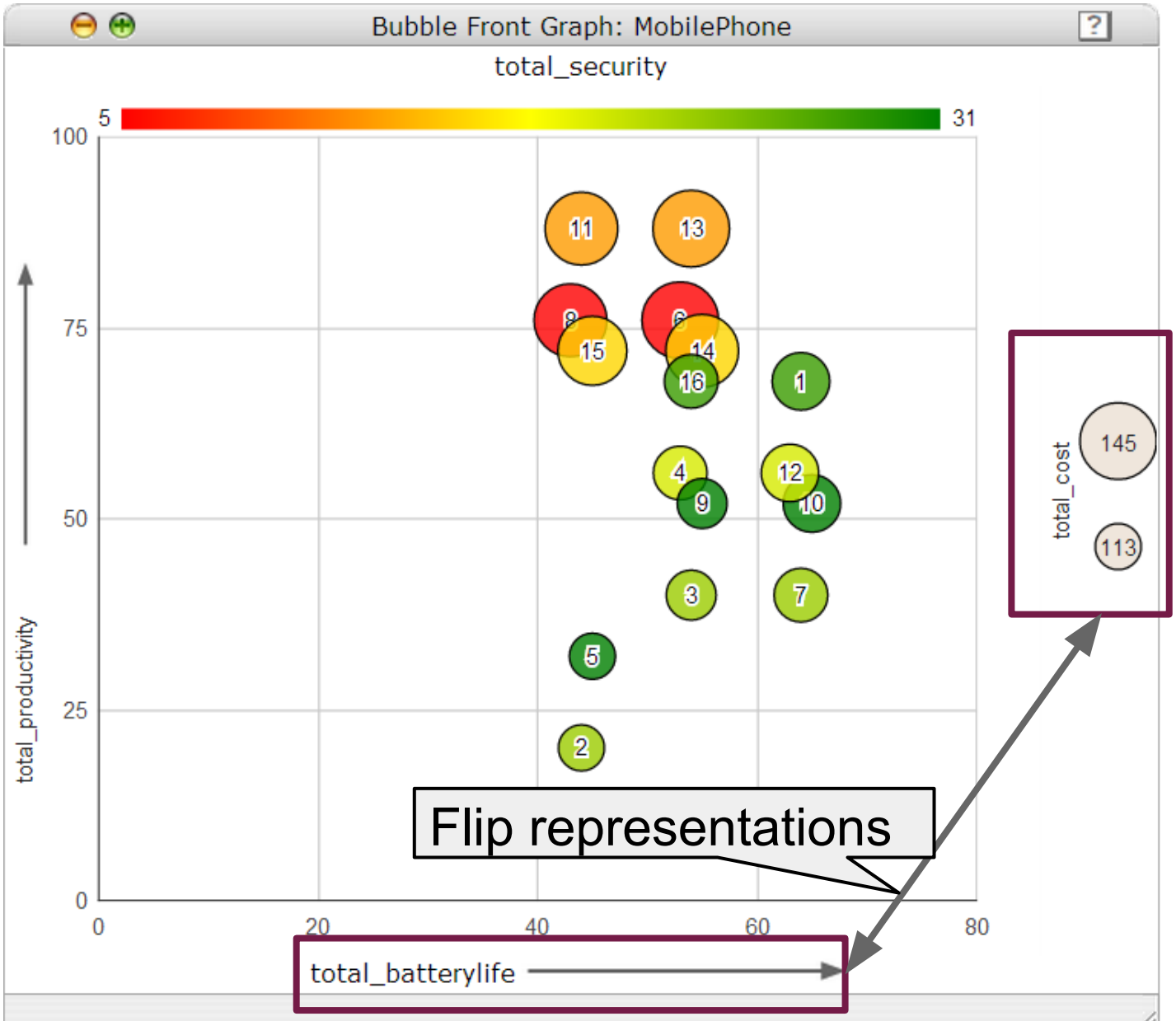
1.2 Sort by Quality



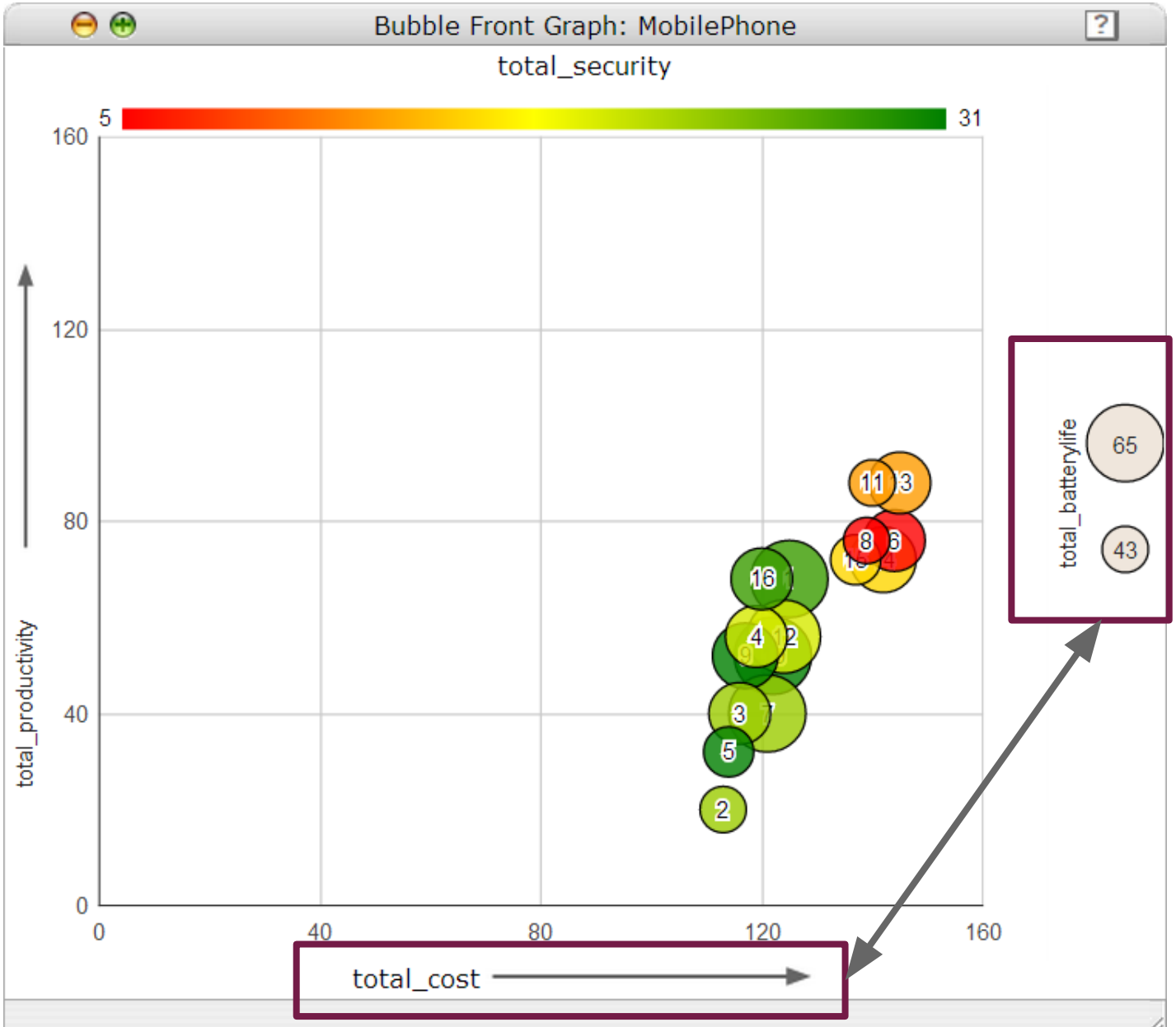
1.2 Sort by Quality



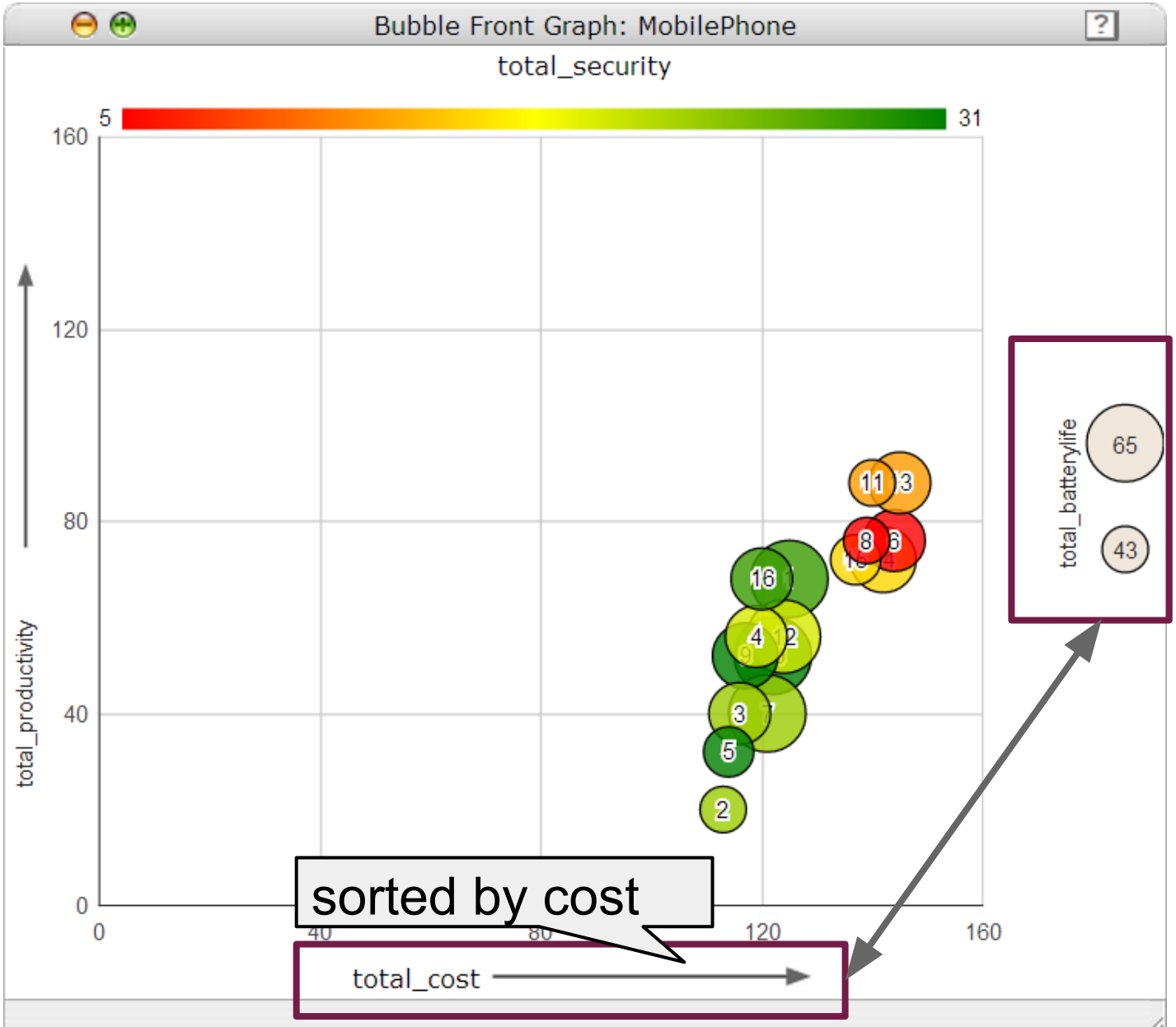
1.2 Sort by Quality



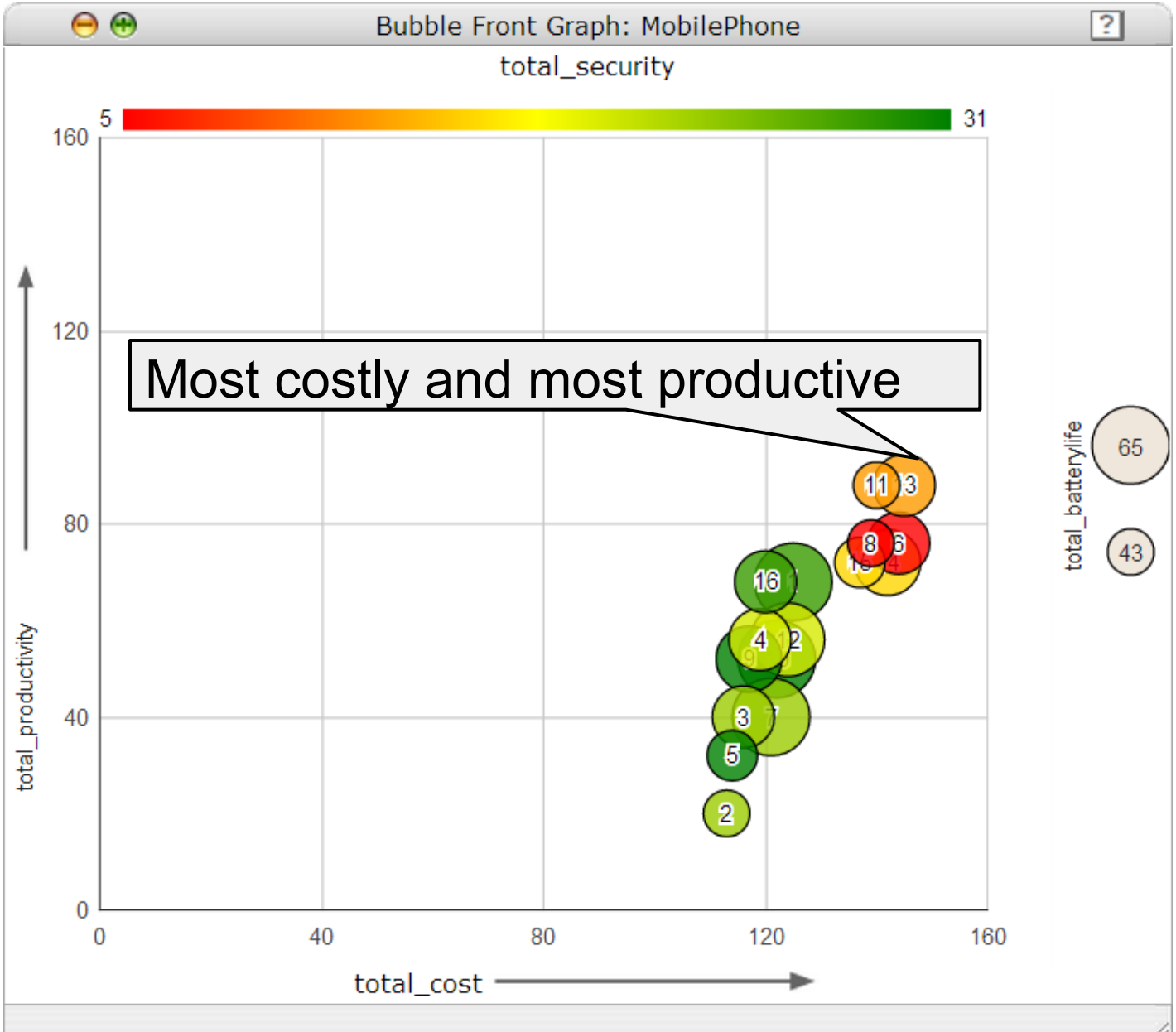
1.2 Sort by Quality



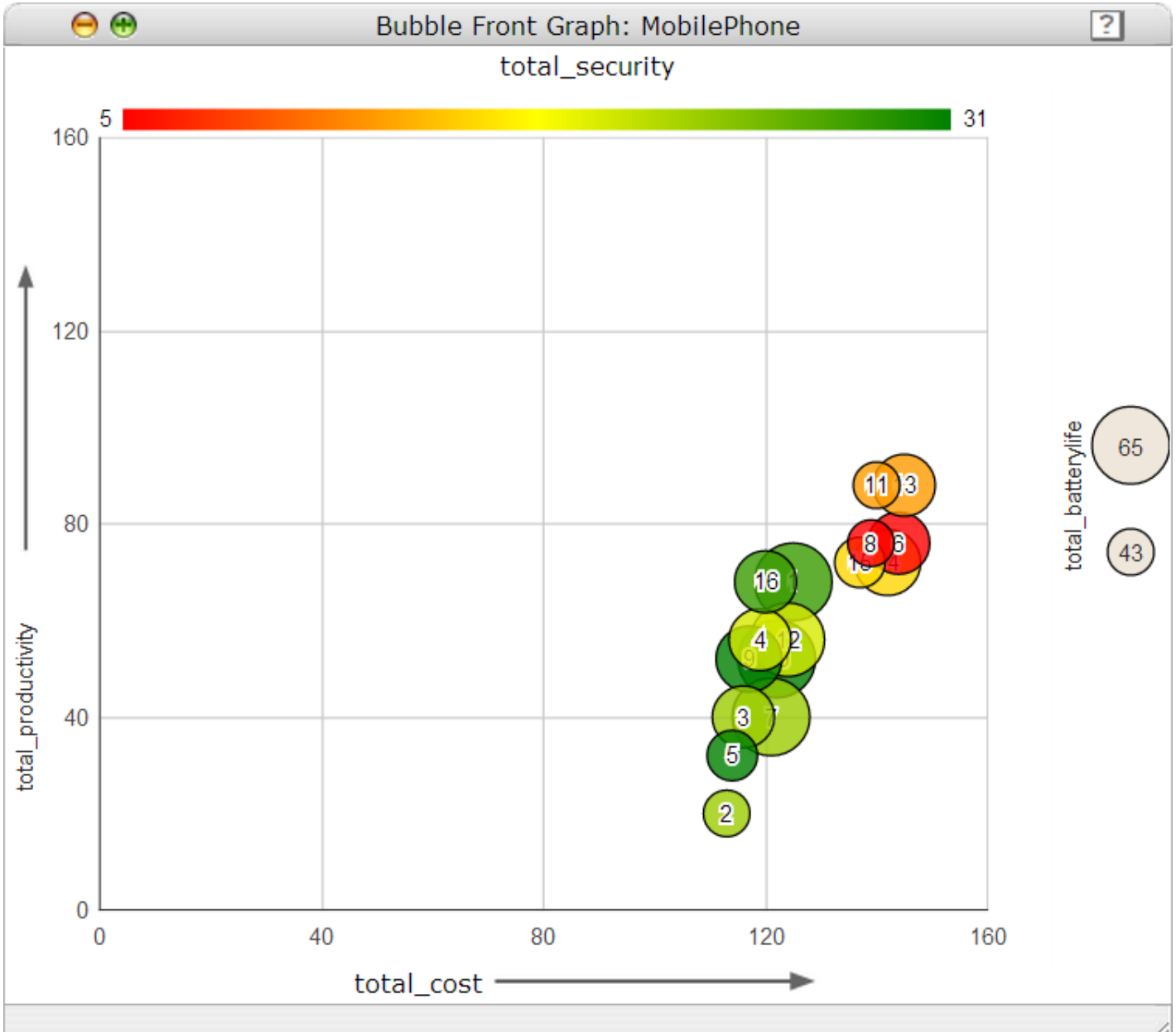
1.2 Sort by Quality



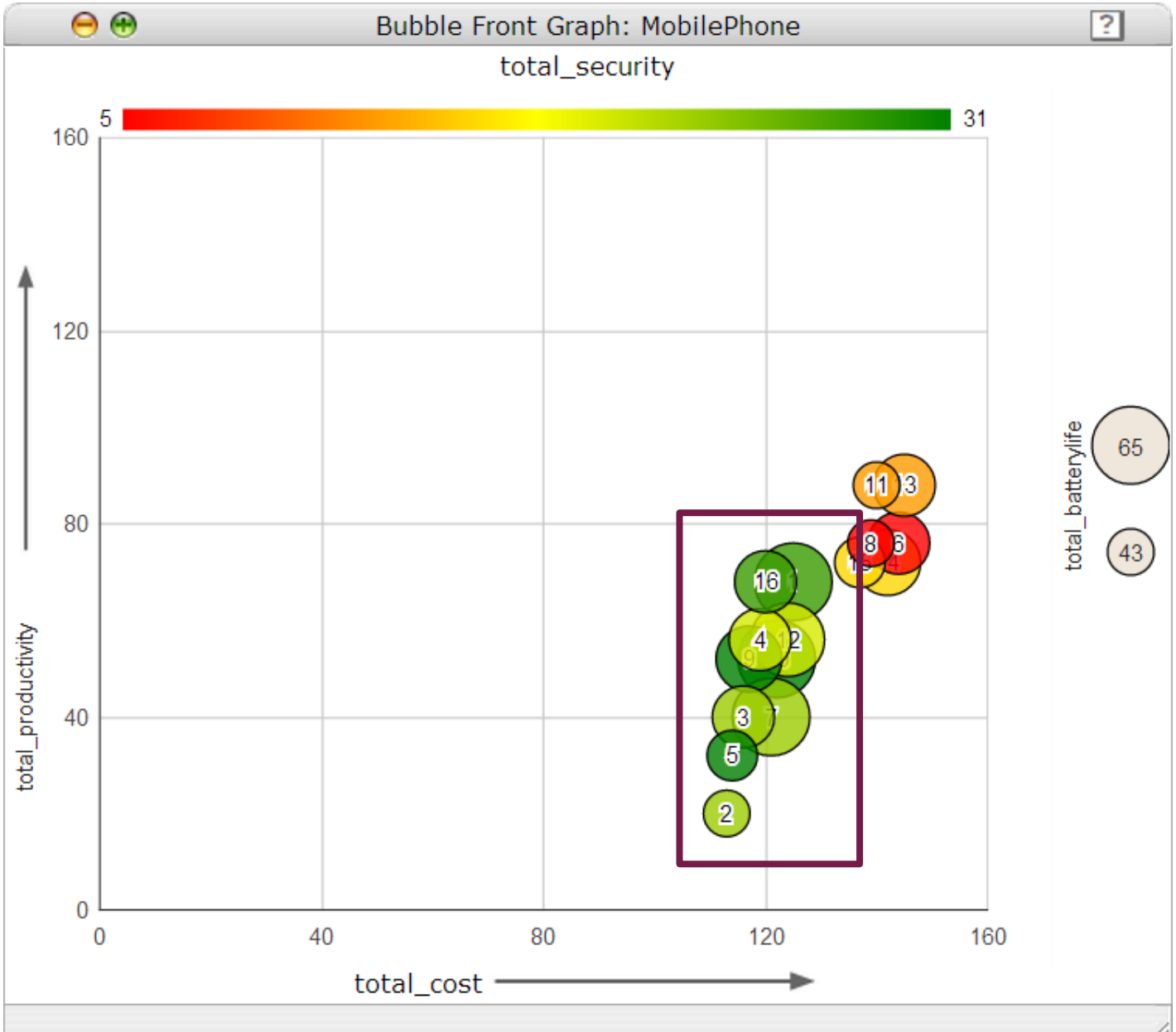
1.2 Sort by Quality



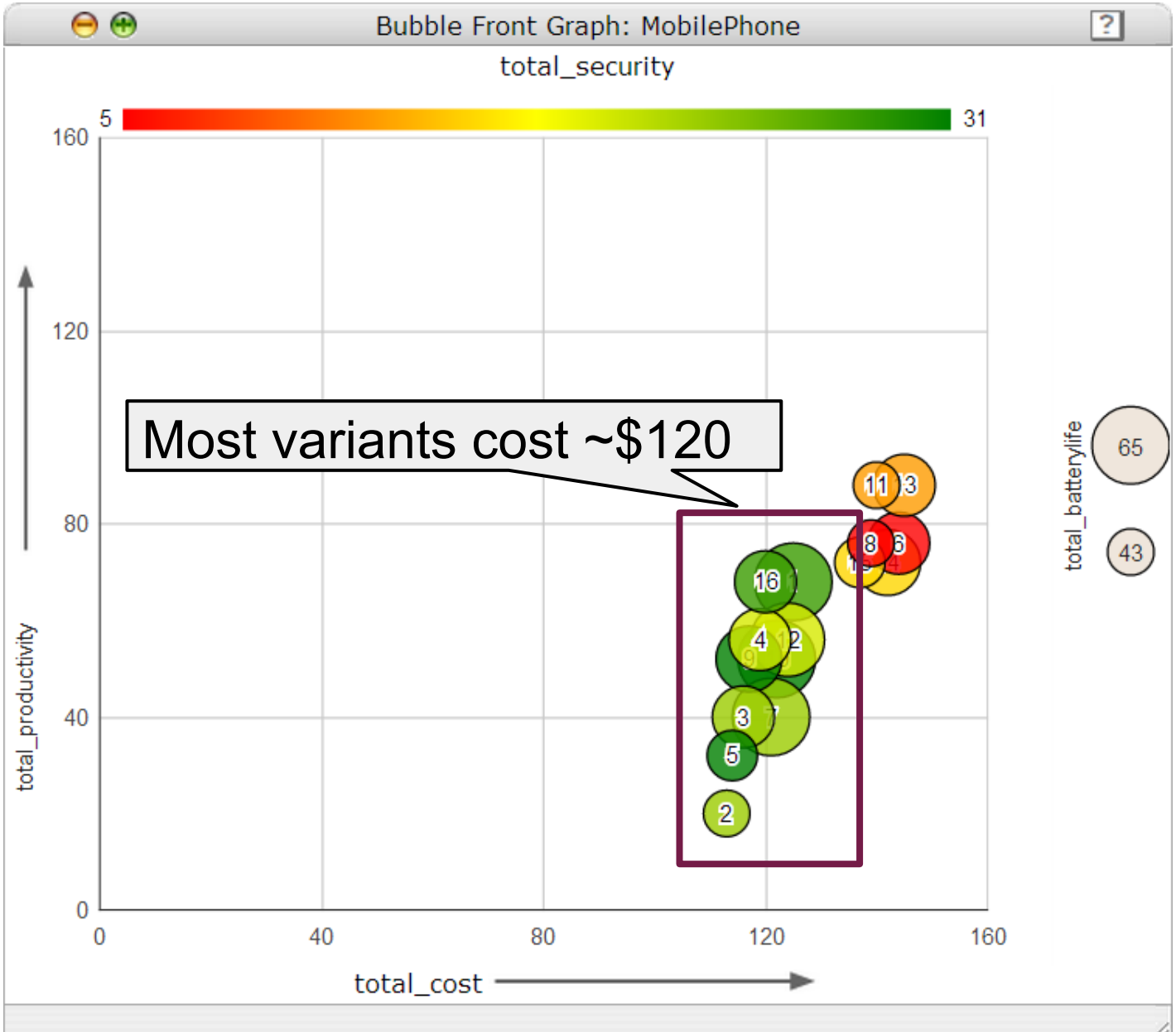
1.3 Distribution of Variants



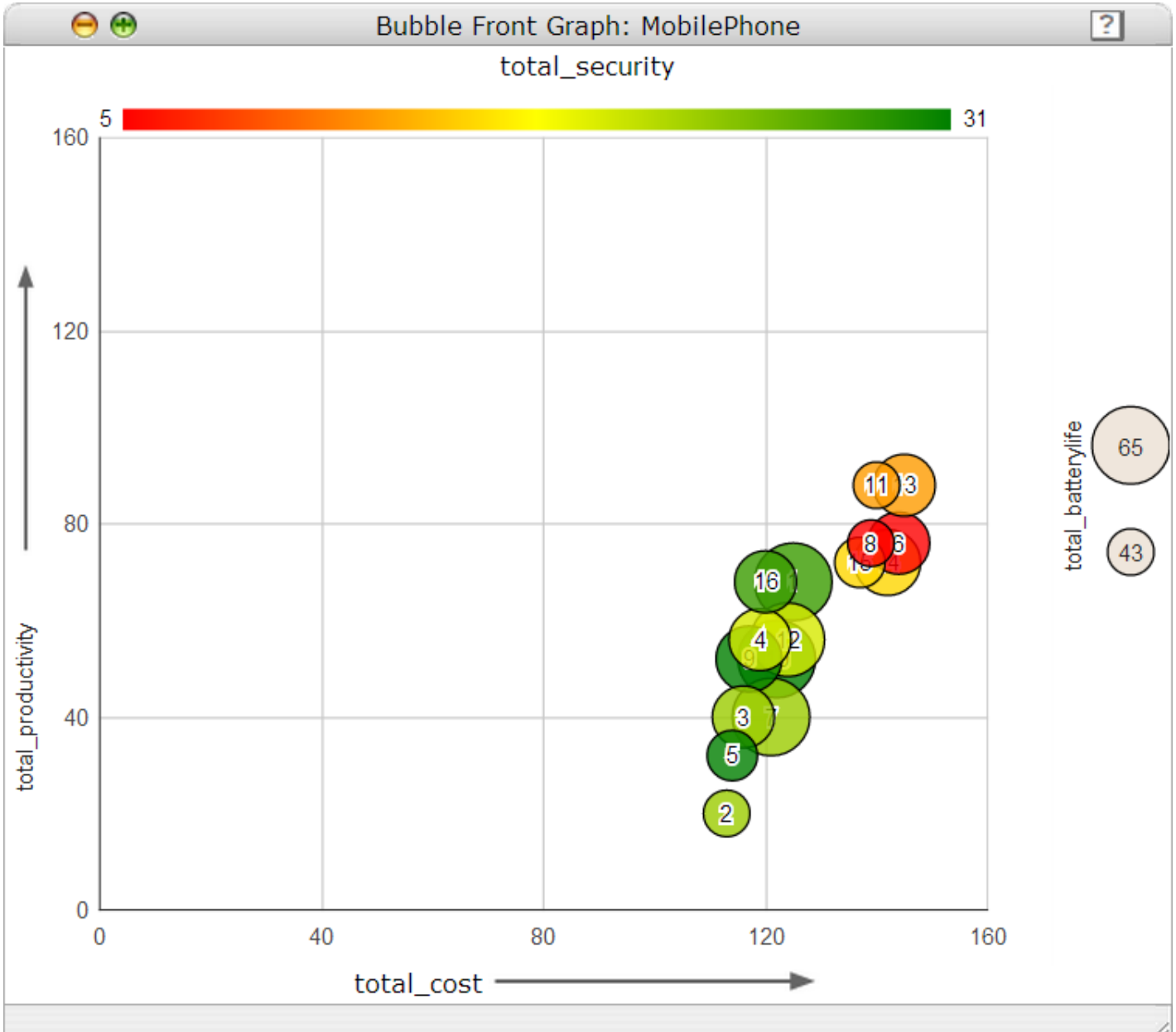
1.3 Distribution of Variants



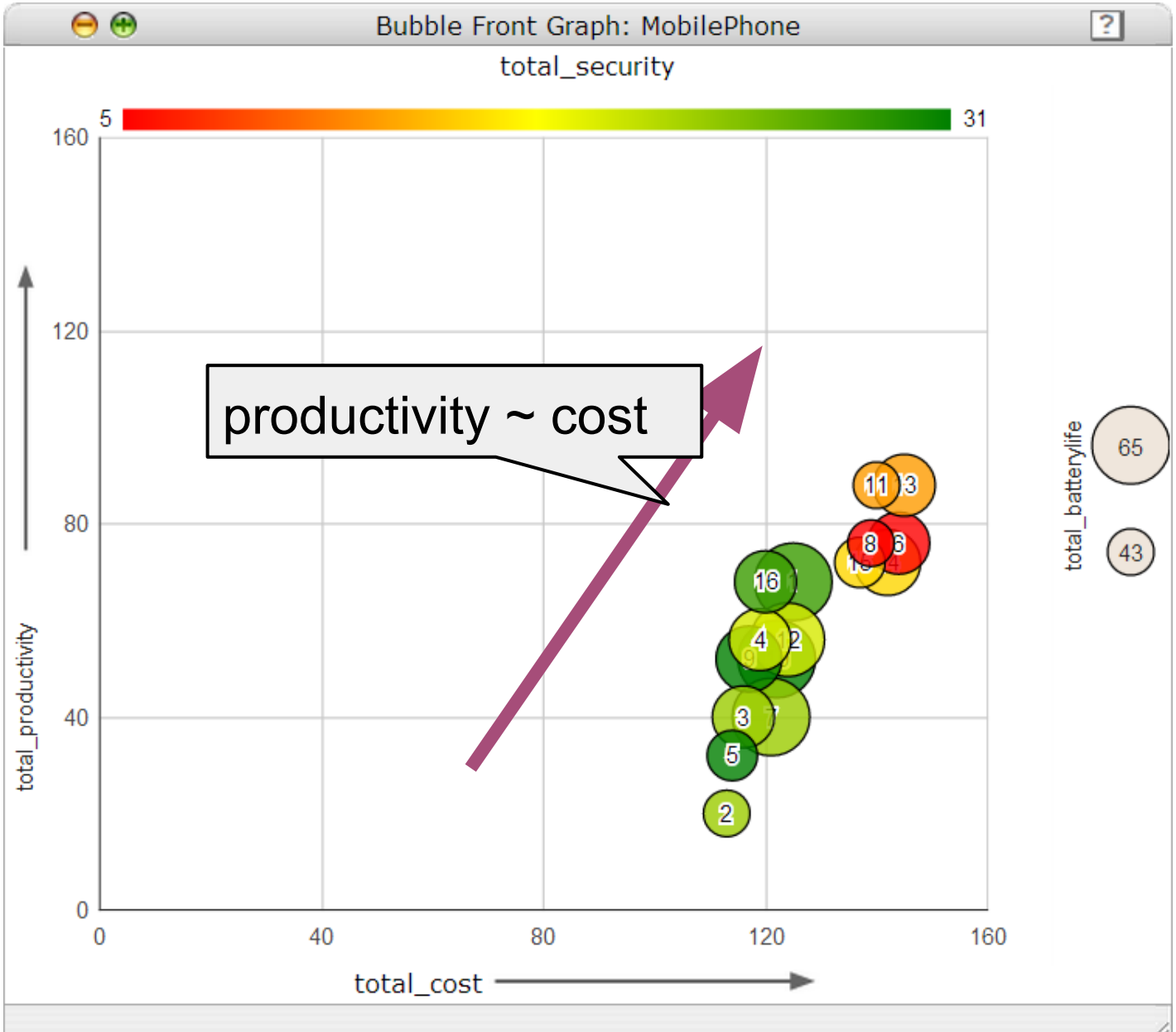
1.3 Distribution of Variants



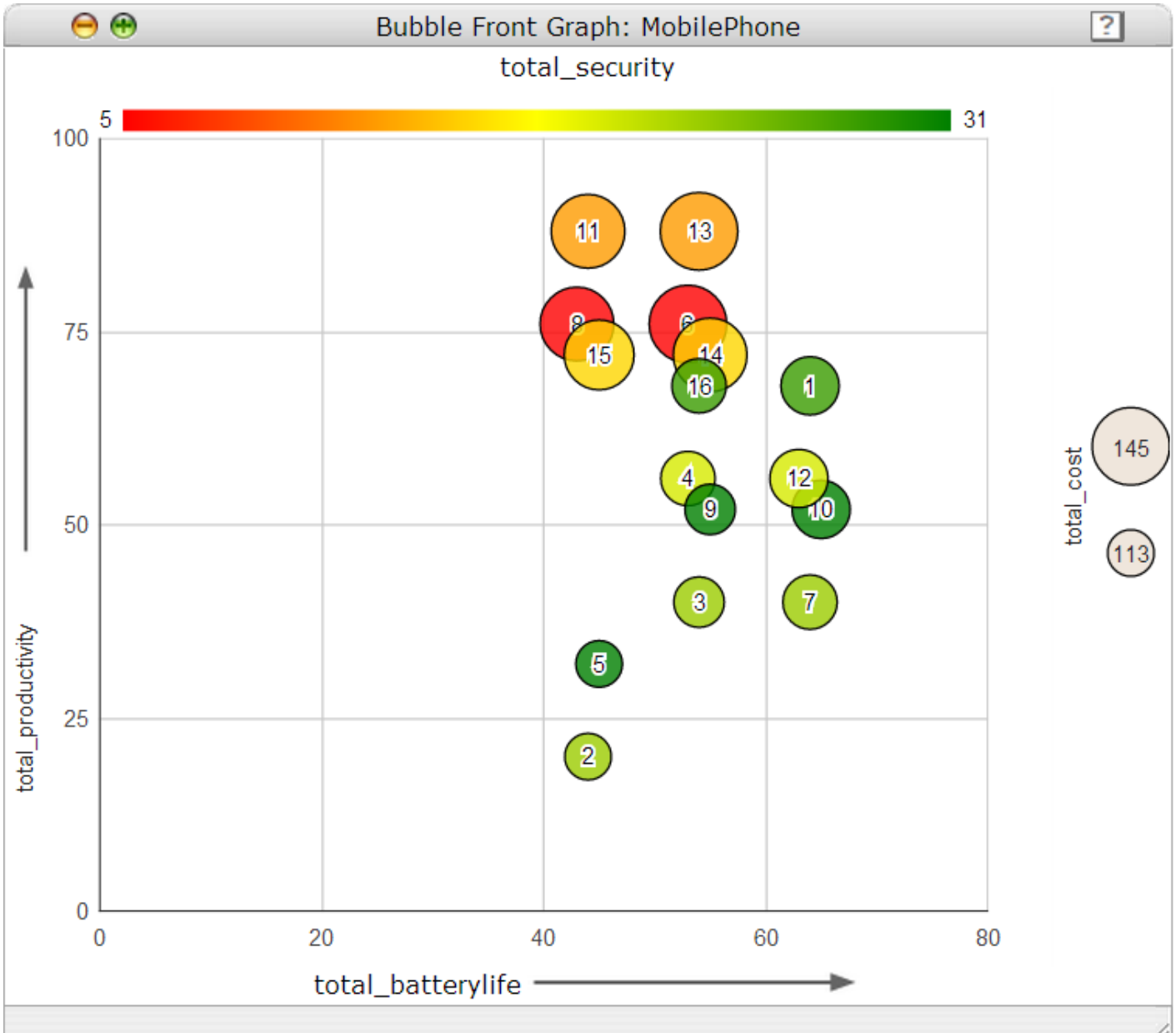
1.4 Correlation Between Qualities



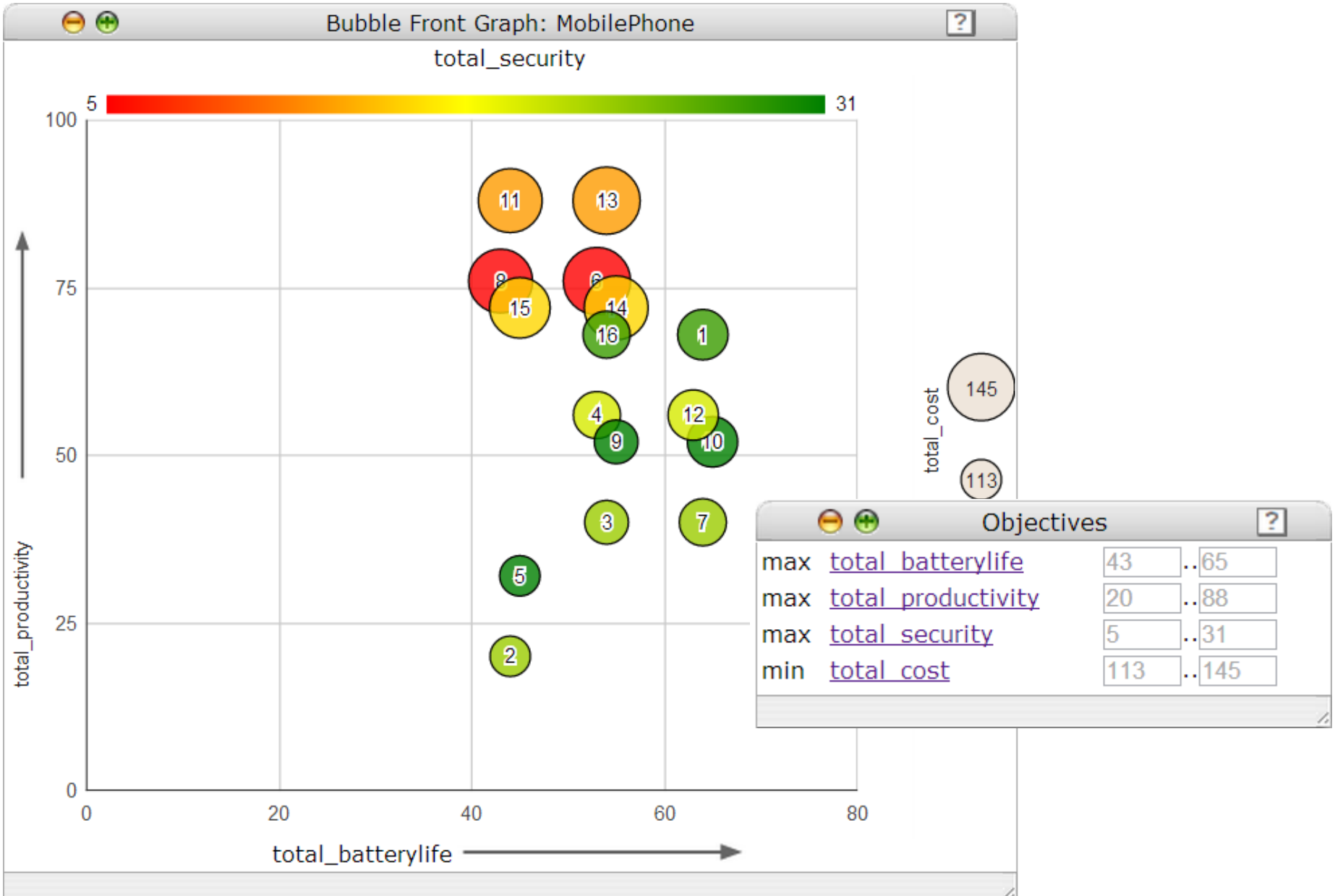
1.4 Correlation Between Qualities



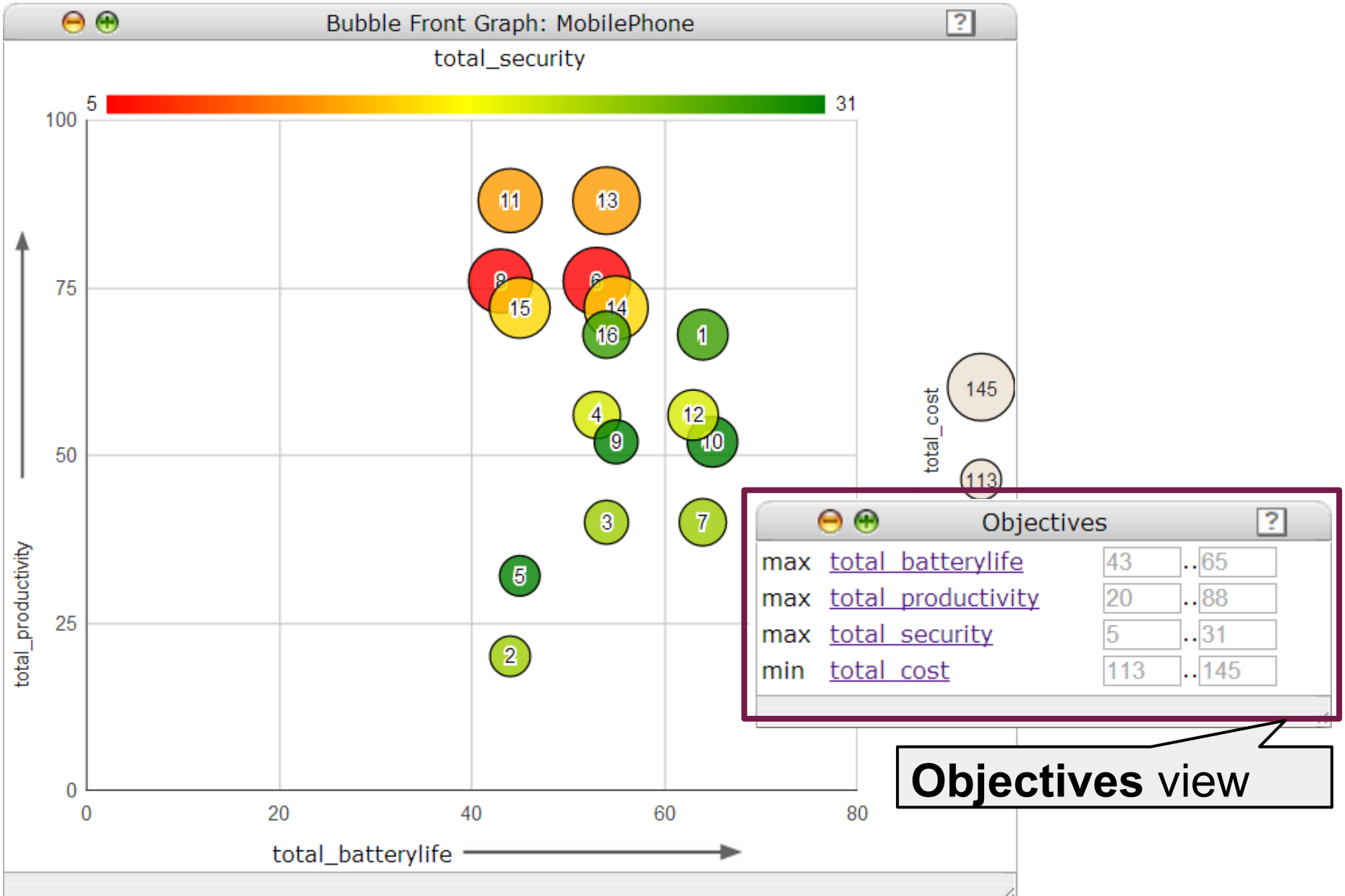
1.5 Filter by Quality



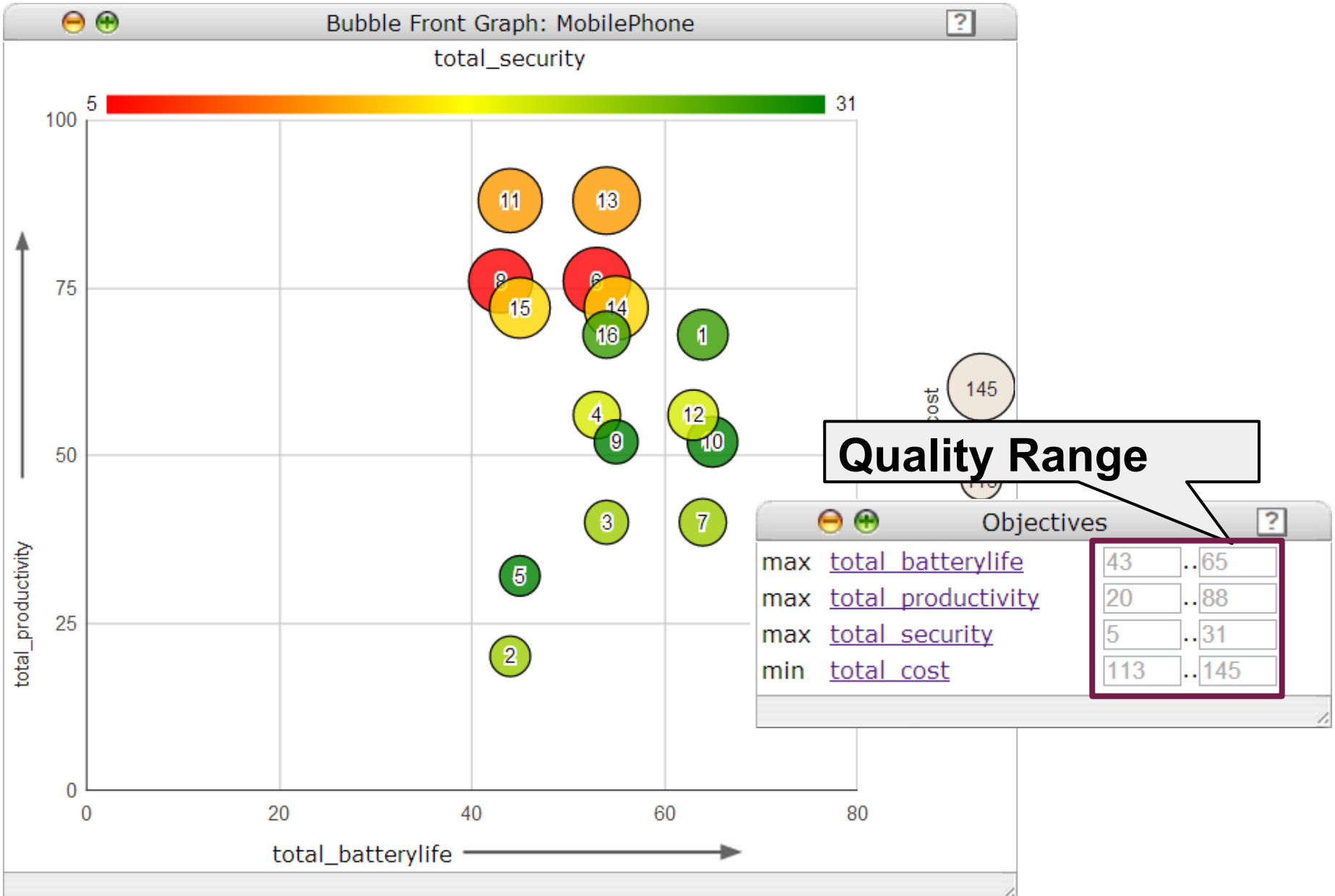
1.5 Filter by Quality



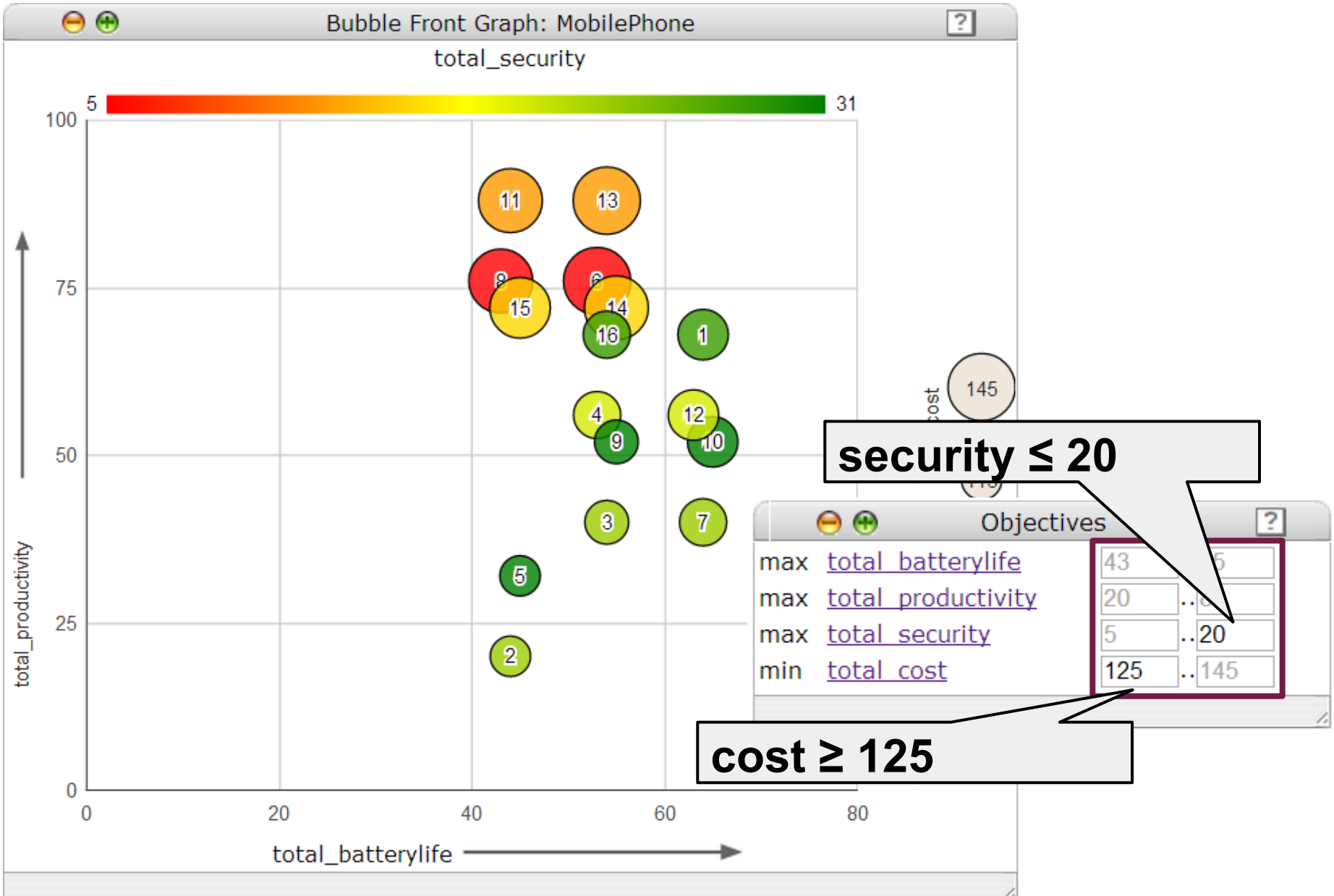
1.5 Filter by Quality



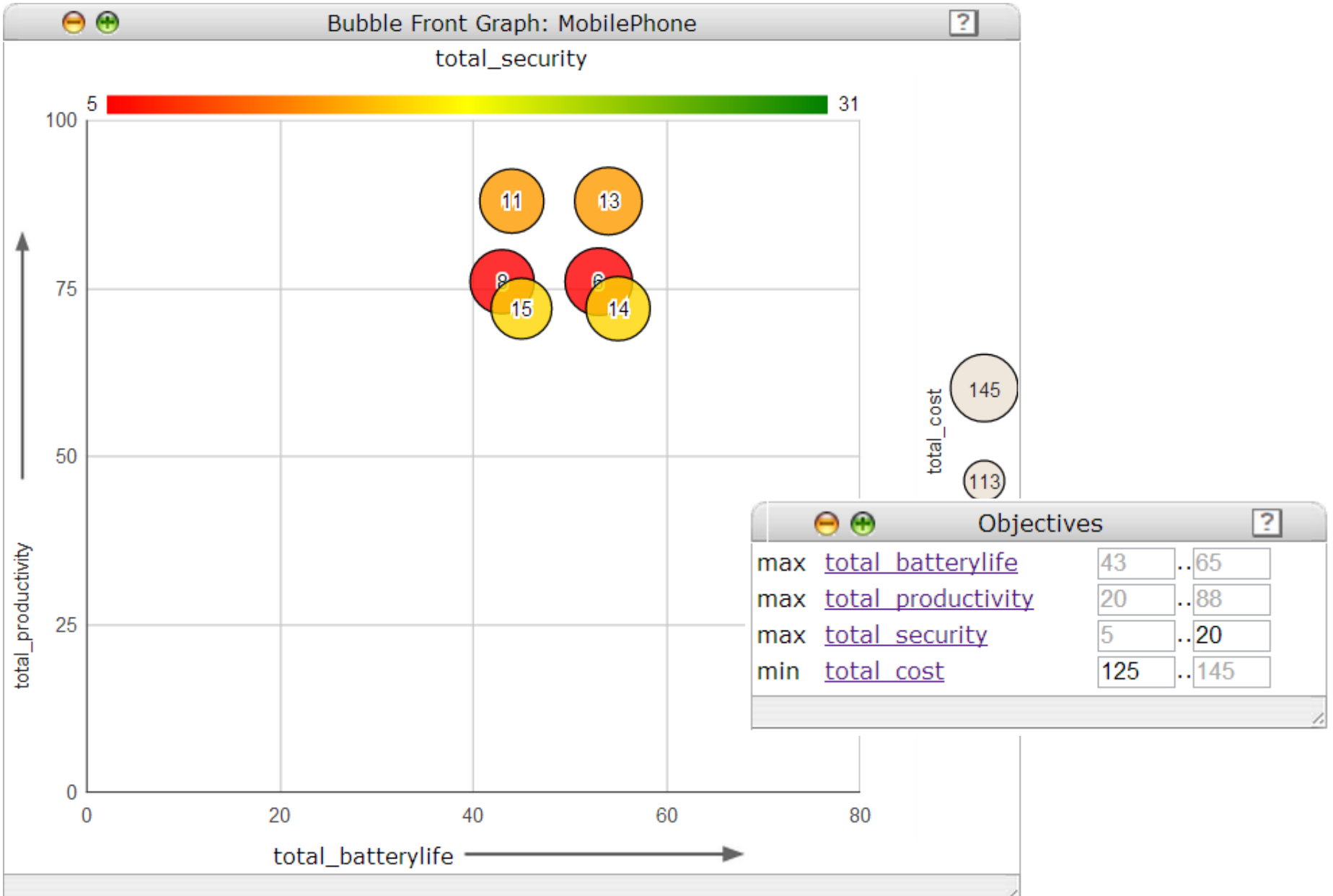
1.5 Filter by Quality



1.5 Filter by Quality



1.5 Filter by Quality



Use Cases (1)

1.1 See quality **ranges**: min and max `batterylife`?

1.2 **Sort** variants by `productivity`?

1.3 See **correlation**: `security ~ cost`?

1.4 See **distribution**: most variants are at which `cost`?

1.5 Get variants **by quality:** with `cost ≥ $125`?

Use Cases (2)

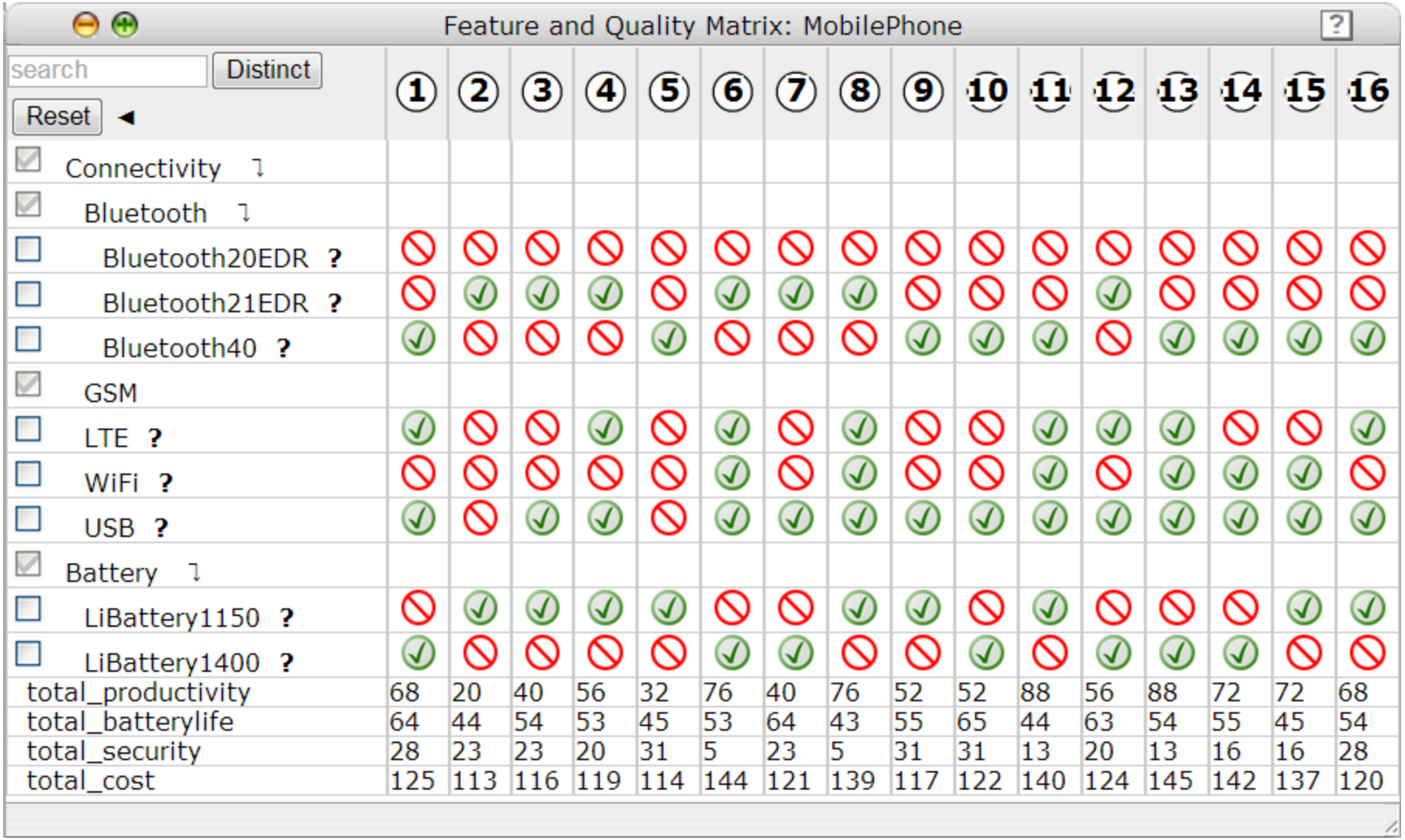
2.1 See feature **occurrences**: is `USB` frequent or rare?

2.2 Get variants **by features**: with `WiFi`, without `LTE`?

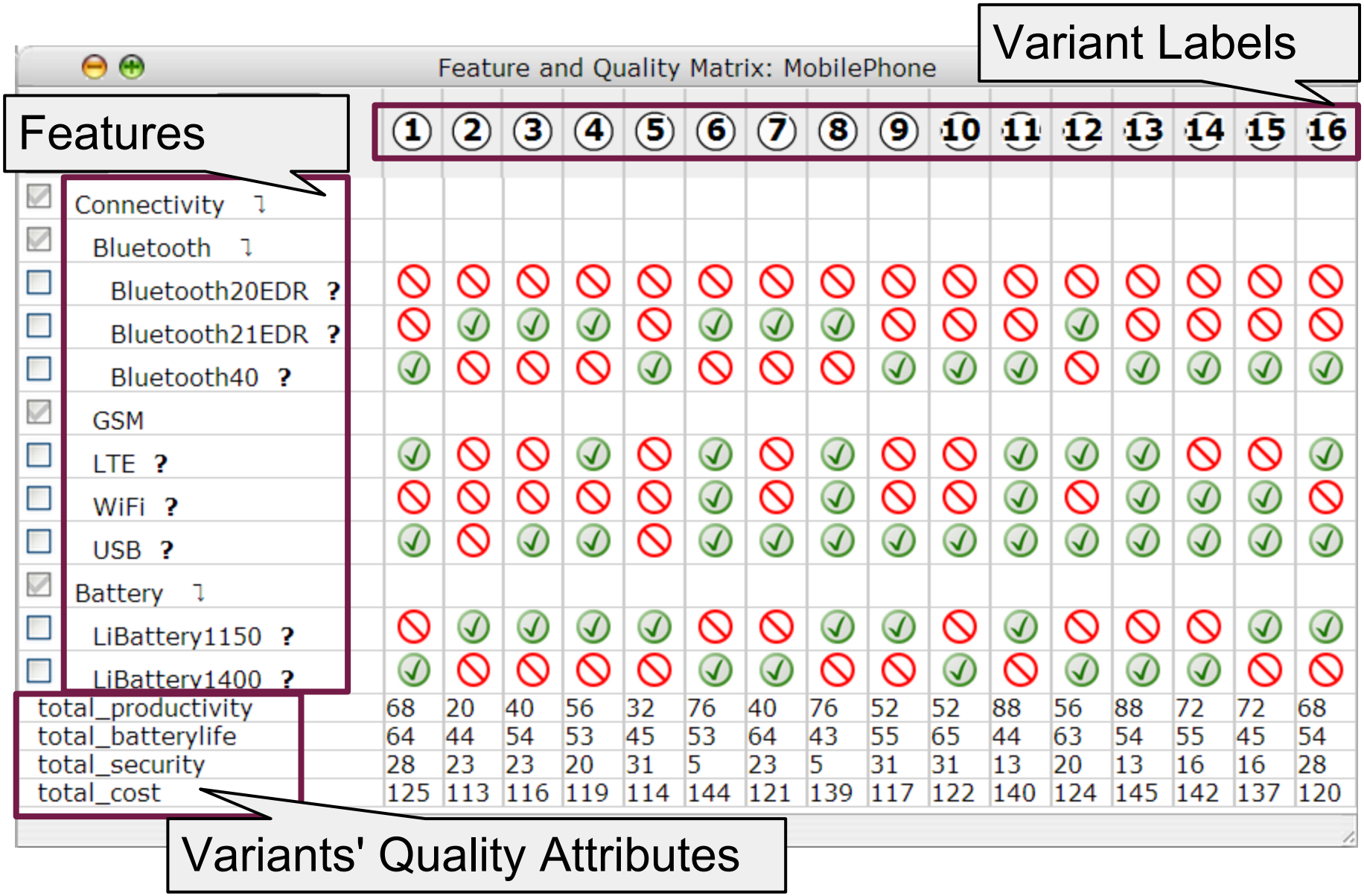
2.3 See **cumulative impact** on quality: `USB + LTE`?

2.4 Choose **desired** variants by features and quality?

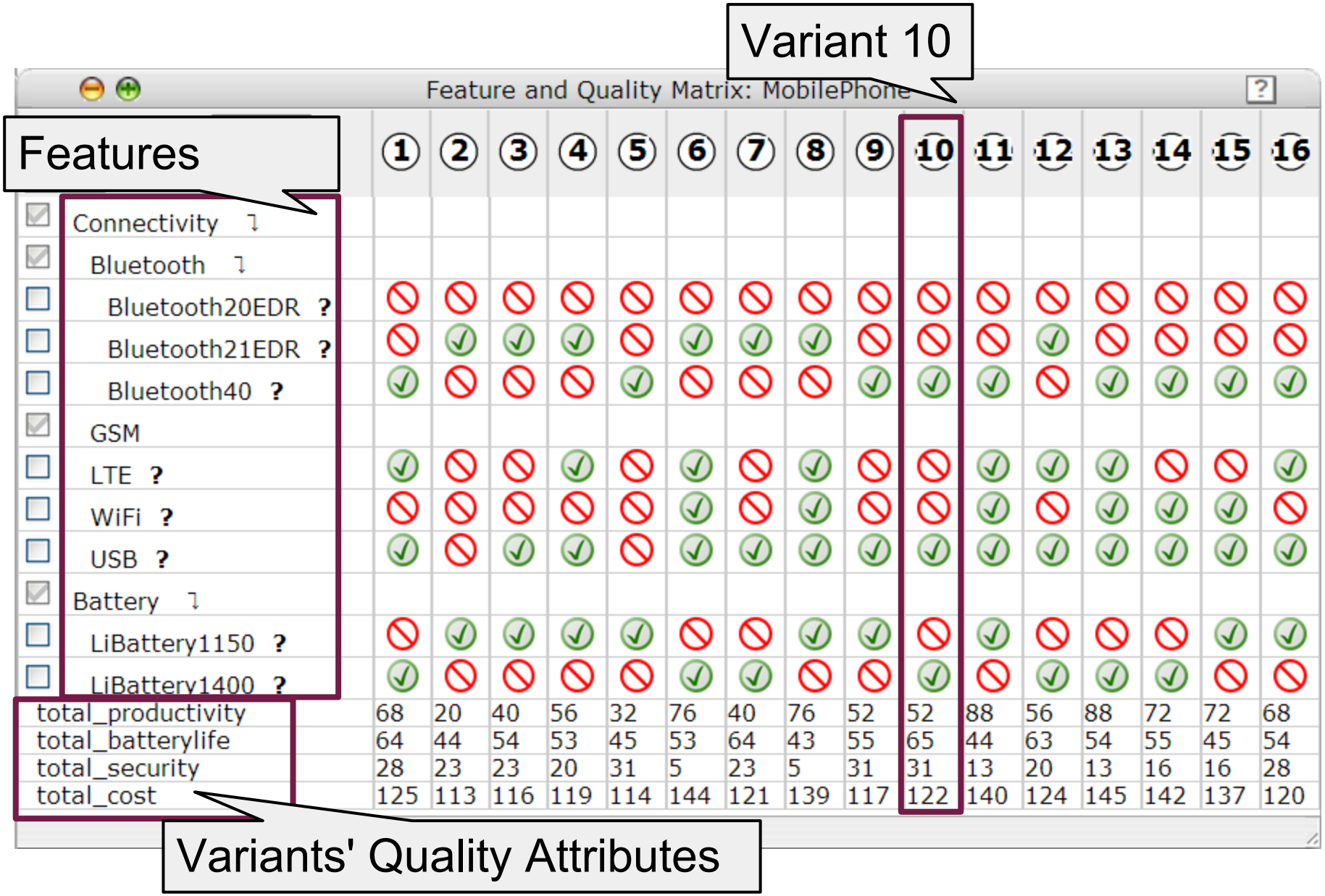
Feature and Quality Matrix



Feature and Quality Matrix

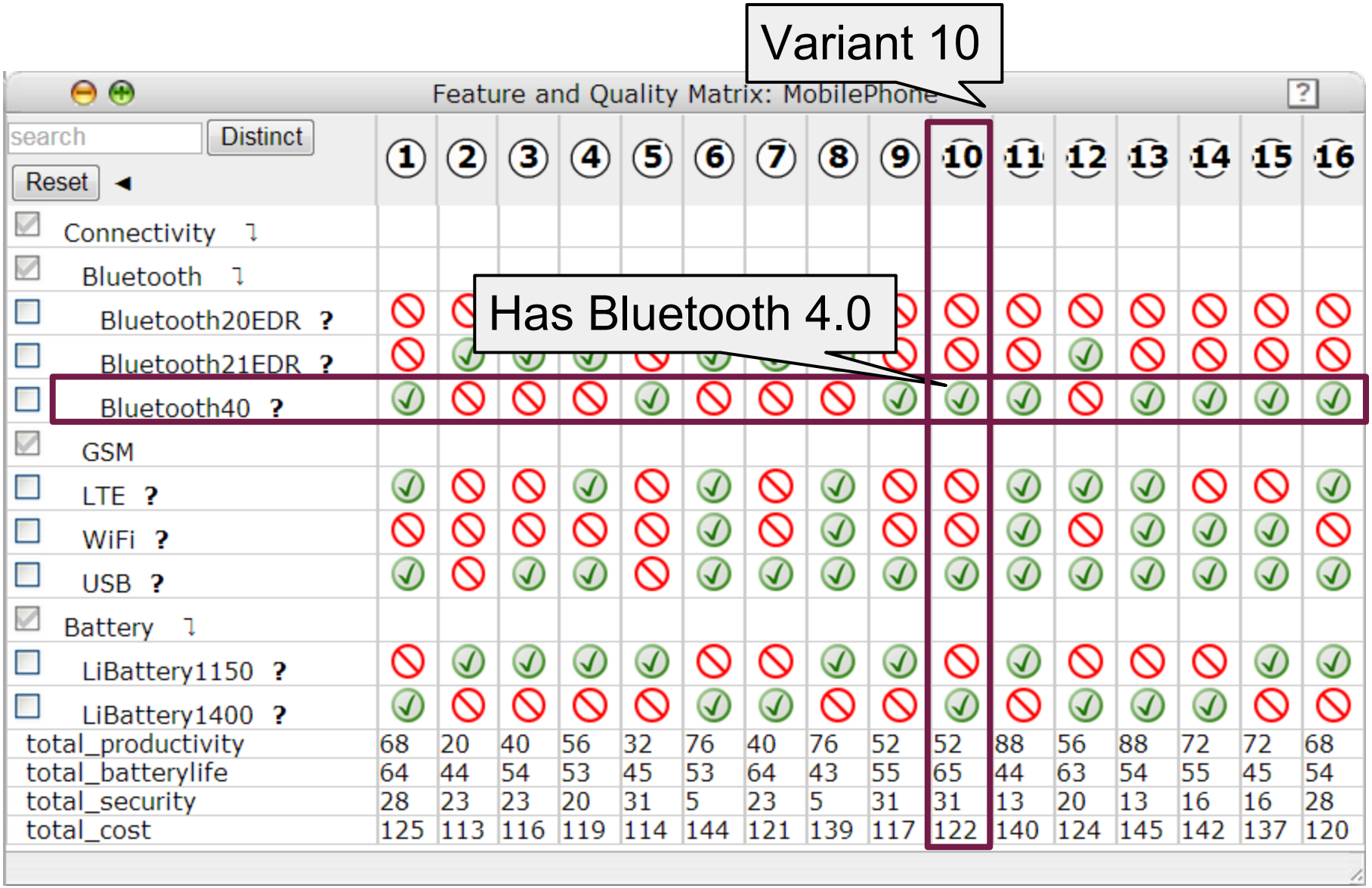


Feature and Quality Matrix

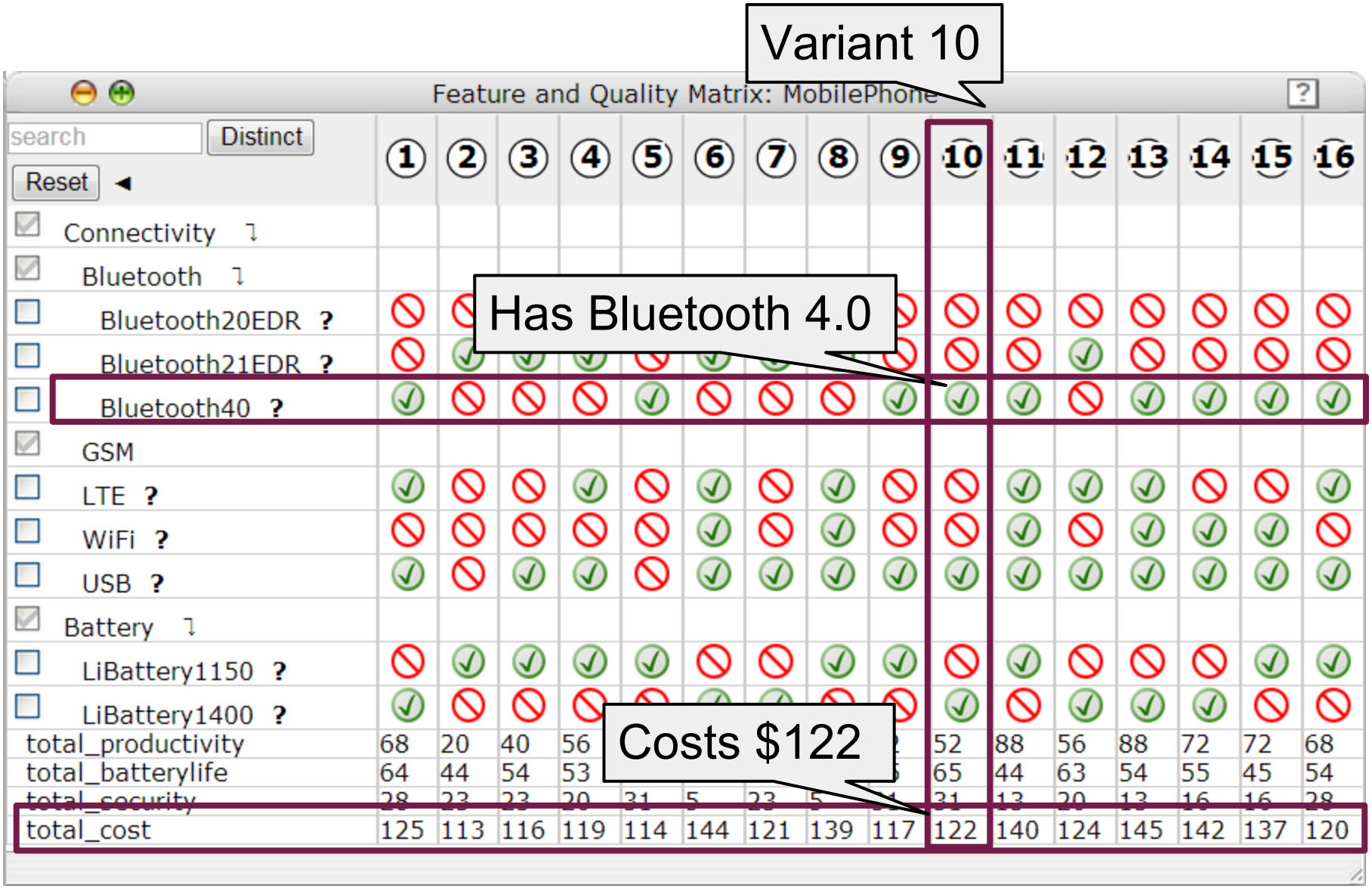


Features	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Connectivity																
Bluetooth																
Bluetooth20EDR ?	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘
Bluetooth21EDR ?	⊘	✓	✓	✓	⊘	✓	✓	✓	⊘	⊘	⊘	✓	⊘	⊘	⊘	⊘
Bluetooth40 ?	✓	⊘	⊘	⊘	✓	⊘	⊘	⊘	✓	✓	✓	⊘	✓	✓	✓	✓
GSM																
LTE ?	✓	⊘	⊘	✓	⊘	✓	⊘	✓	⊘	⊘	✓	✓	✓	⊘	⊘	✓
WiFi ?	⊘	⊘	⊘	⊘	⊘	✓	⊘	✓	⊘	⊘	✓	⊘	✓	✓	✓	⊘
USB ?	✓	⊘	✓	✓	⊘	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Battery																
LiBattery1150 ?	⊘	✓	✓	✓	✓	⊘	⊘	✓	✓	⊘	✓	⊘	⊘	⊘	✓	✓
LiBattery1400 ?	✓	⊘	⊘	⊘	⊘	✓	✓	⊘	⊘	✓	⊘	✓	✓	✓	⊘	⊘
total_productivity	68	20	40	56	32	76	40	76	52	52	88	56	88	72	72	68
total_batterylife	64	44	54	53	45	53	64	43	55	65	44	63	54	55	45	54
total_security	28	23	23	20	31	5	23	5	31	31	13	20	13	16	16	28
total_cost	125	113	116	119	114	144	121	139	117	122	140	124	145	142	137	120

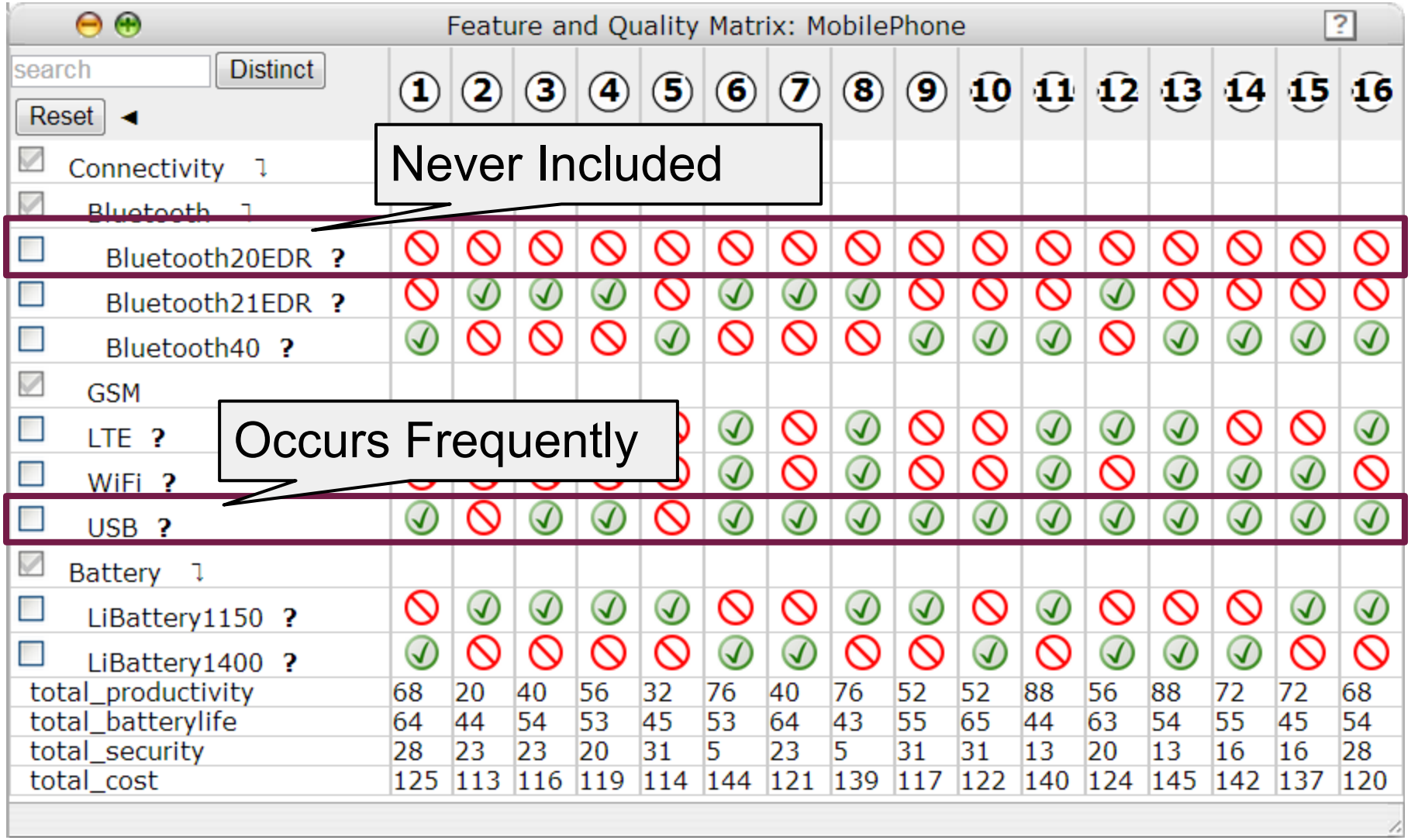
Feature and Quality Matrix



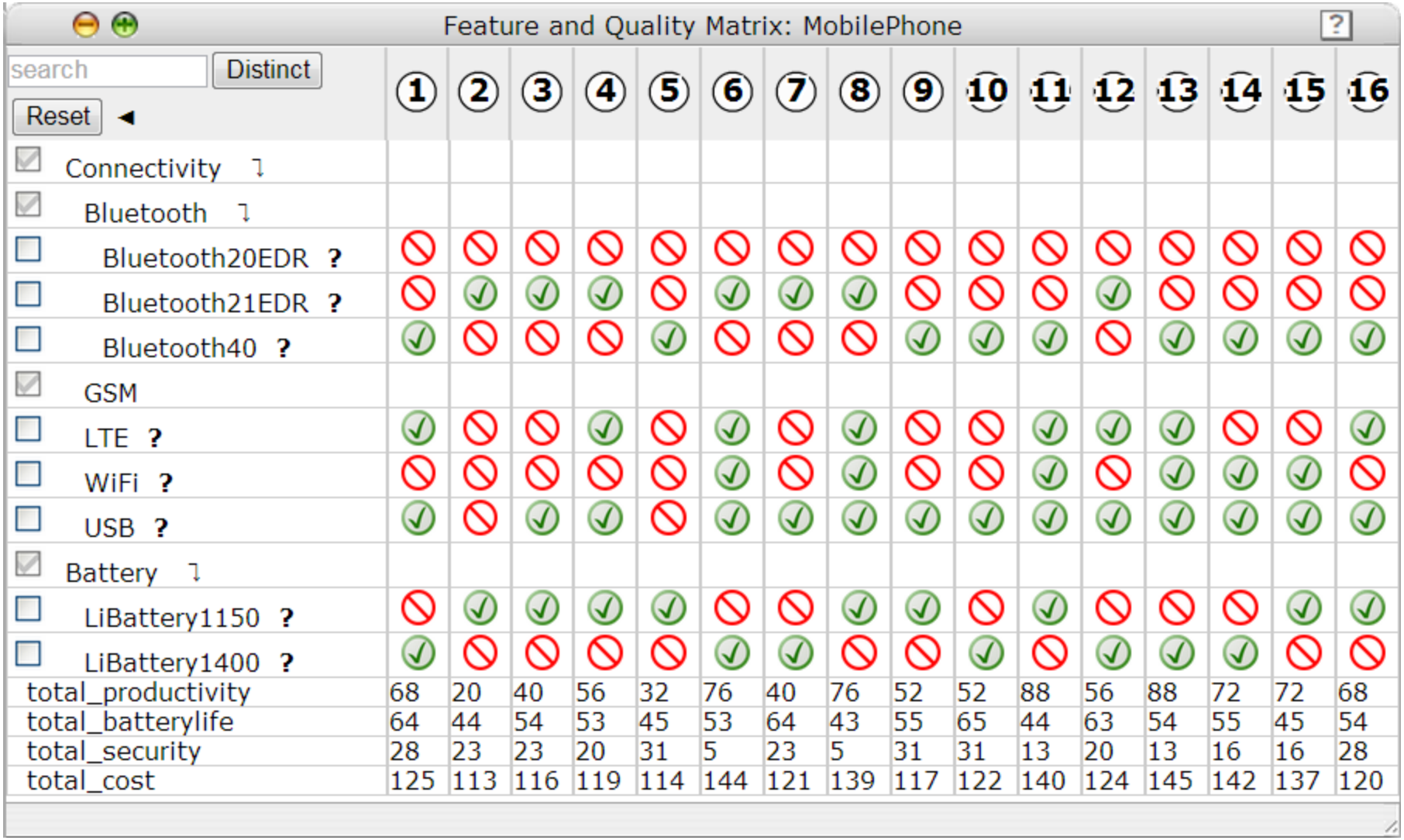
Feature and Quality Matrix



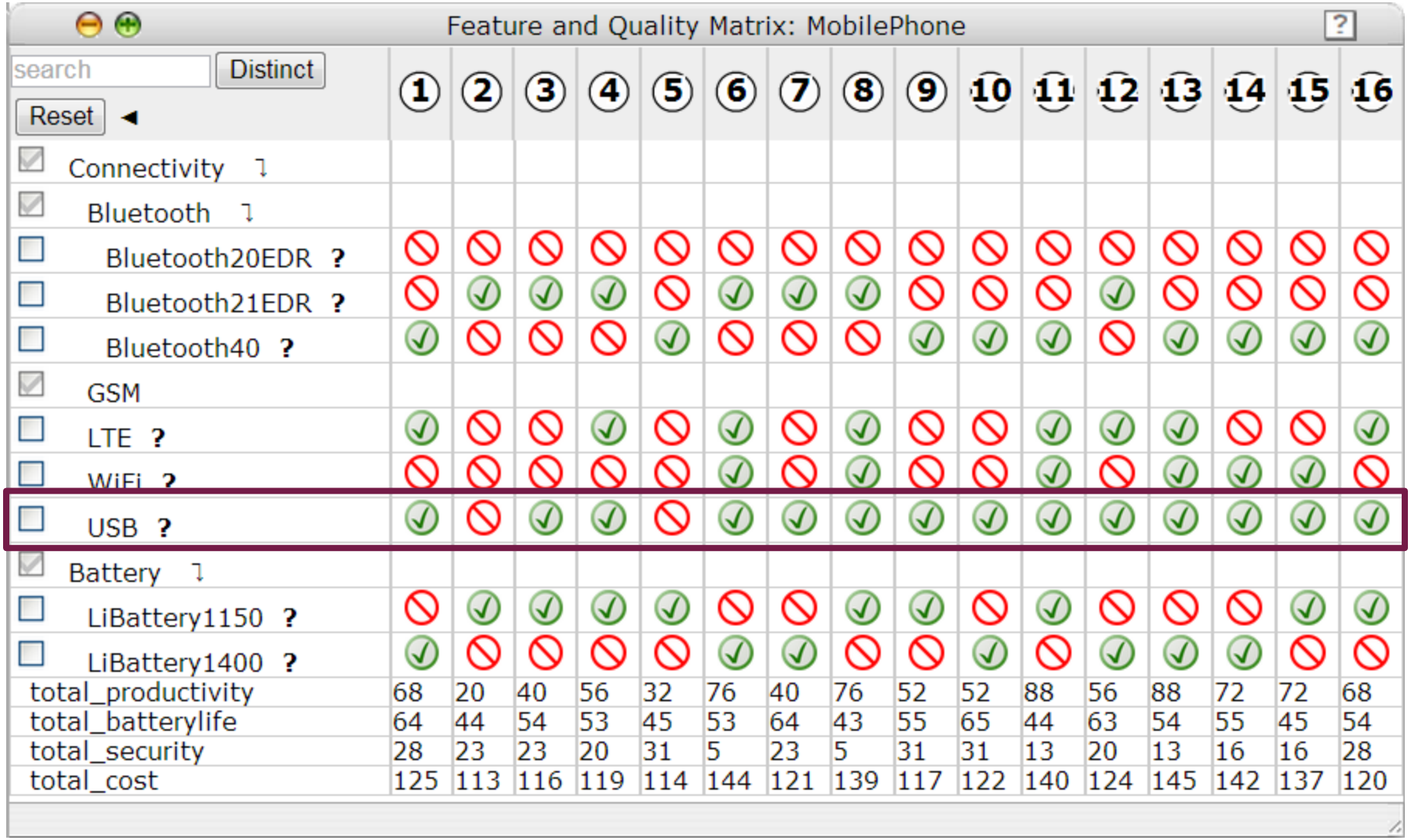
2.1 See Feature Occurrences



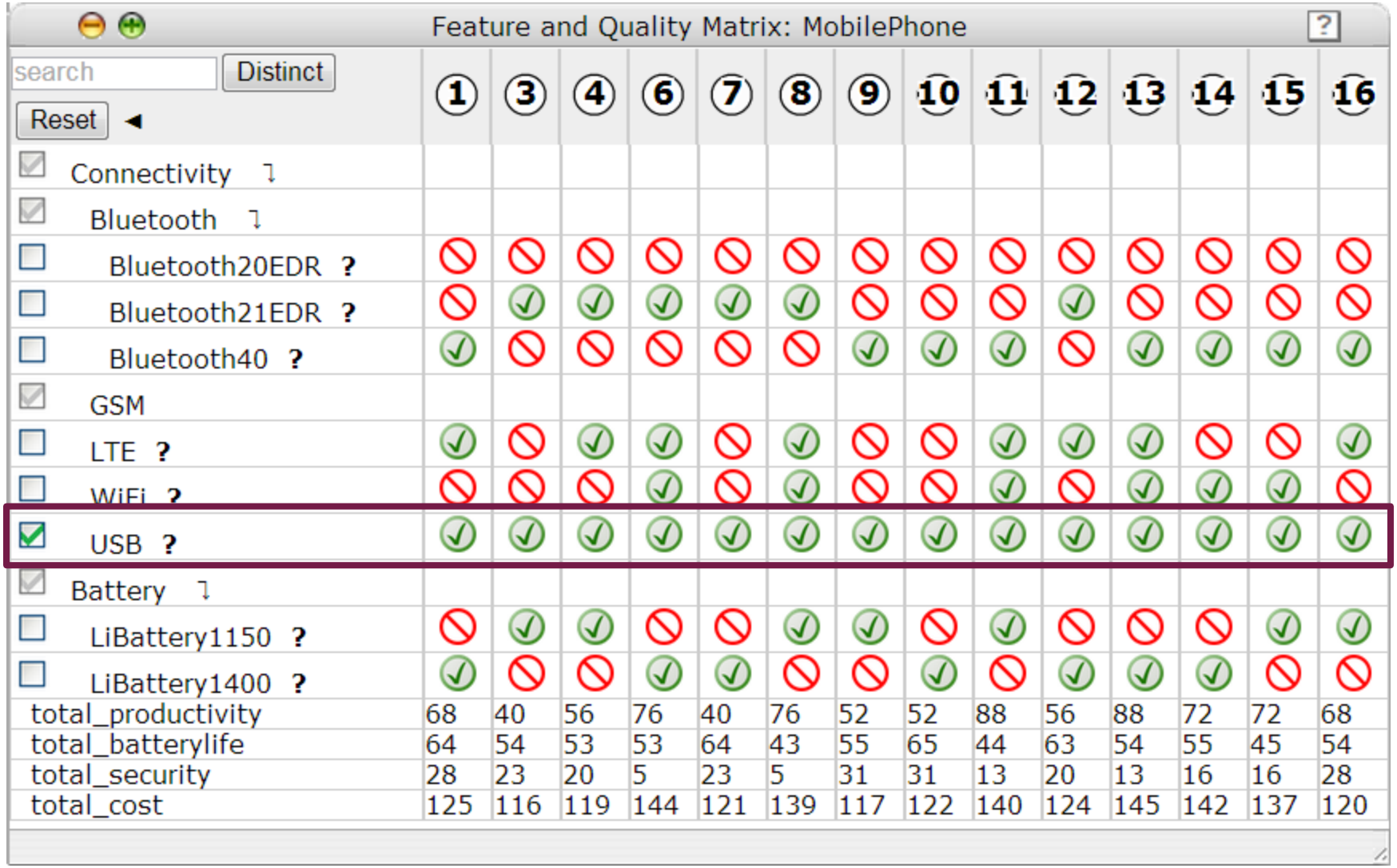
2.2 Get Variants by Features



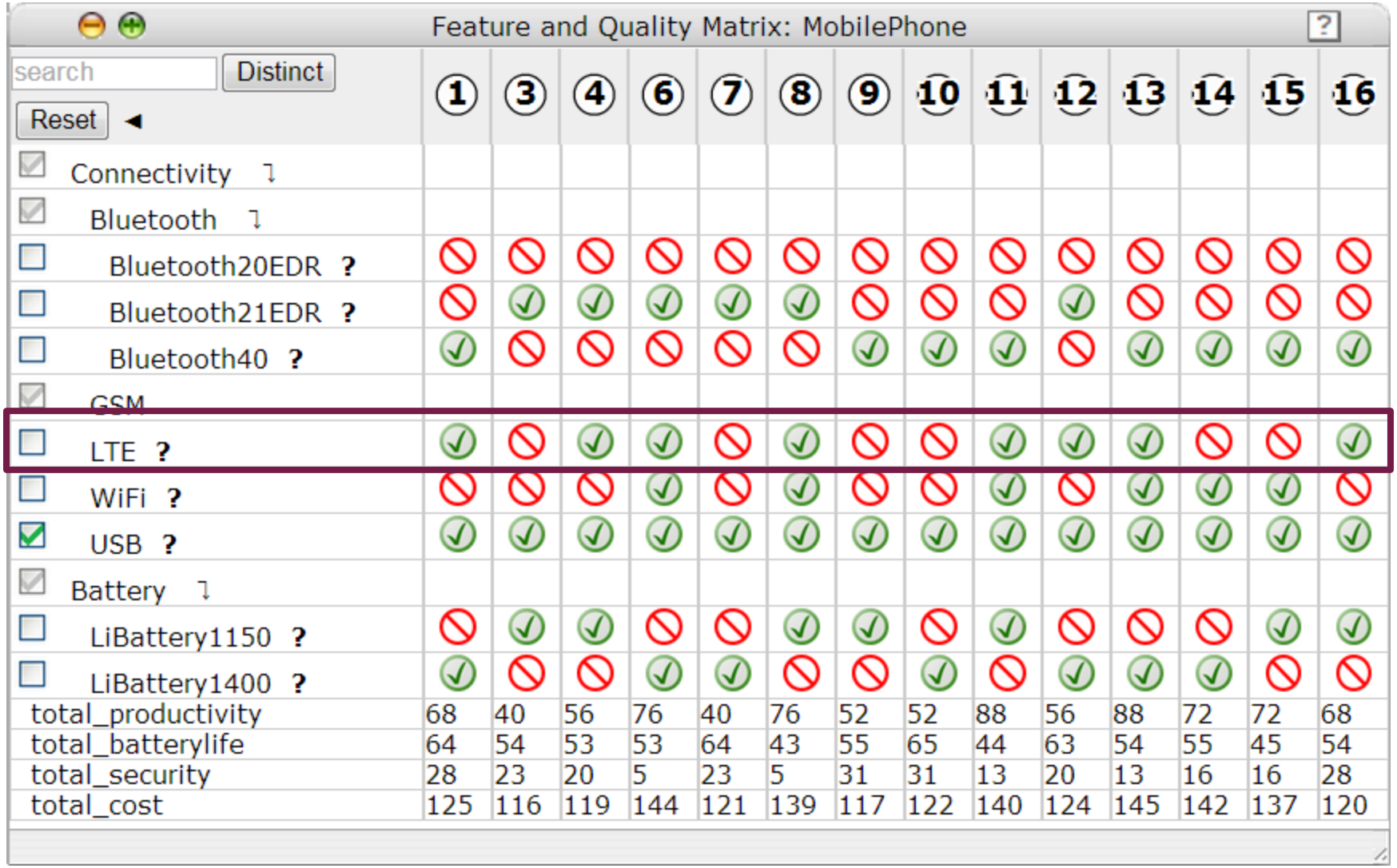
2.2 Get Variants by Features



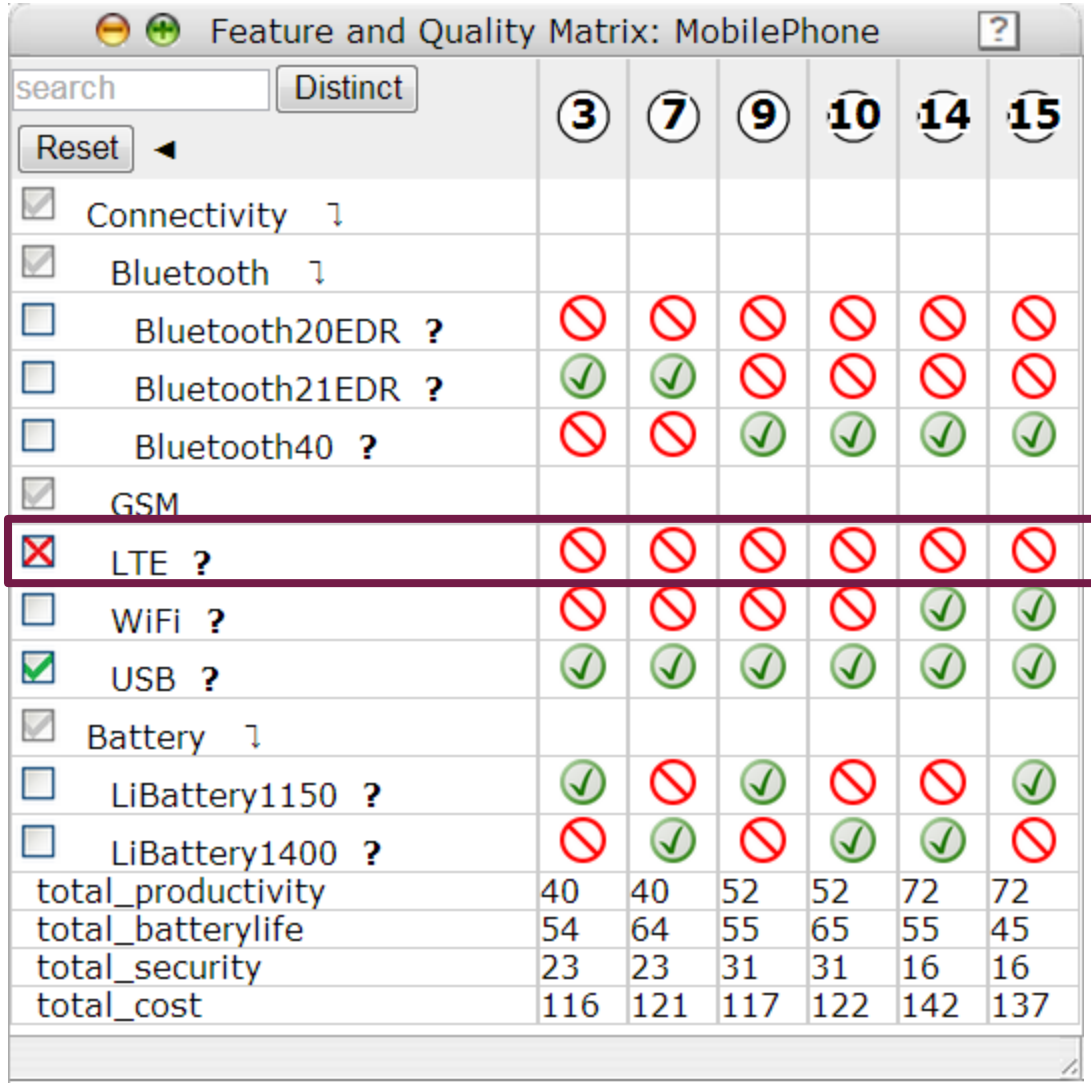
2.2 Get Variants by Features



2.2 Get Variants by Features



2.2 Get Variants by Features



Feature and Quality Matrix: MobilePhone

search | Distinct | Reset

	3	7	9	10	14	15
Connectivity						
Bluetooth						
Bluetooth20EDR ?	✗	✗	✗	✗	✗	✗
Bluetooth21EDR ?	✓	✓	✗	✗	✗	✗
Bluetooth40 ?	✗	✗	✓	✓	✓	✓
GSM						
LTE ?	✗	✗	✗	✗	✗	✗
WiFi ?	✗	✗	✗	✗	✓	✓
USB ?	✓	✓	✓	✓	✓	✓
Battery						
LiBattery1150 ?	✓	✗	✓	✗	✗	✓
LiBattery1400 ?	✗	✓	✗	✓	✓	✗
total_productivity	40	40	52	52	72	72
total_batterylife	54	64	55	65	55	45
total_security	23	23	31	31	16	16
total_cost	116	121	117	122	142	137

2.3 See Cumulative Impact

Feature and Quality Matrix: MobilePhone

search | Distinct | Reset

	3	7	9	10	14	15
Connectivity						
Bluetooth						
Bluetooth20EDR ?	✗	✗	✗	✗	✗	✗
Bluetooth21EDR ?	✓	✓	✗	✗	✗	✗
Bluetooth40 ?	✗	✗	✓	✓	✓	✓
GSM						
LTE ?	✗	✗	✗	✗	✗	✗
WiFi ?	✗	✗	✗	✗	✓	✓
USB ?	✓	✓	✓	✓	✓	✓
Battery						
LiBattery1150 ?	✓	✗	✓	✗	✗	✓
LiBattery1400 ?	✗	✓	✗	✓	✓	✗
total_productivity	40	40	52	52	72	72
total_batterylife	54	64	55	65	55	45
total_security	23	23	31	31	16	16
total_cost	116	121	117	122	142	137

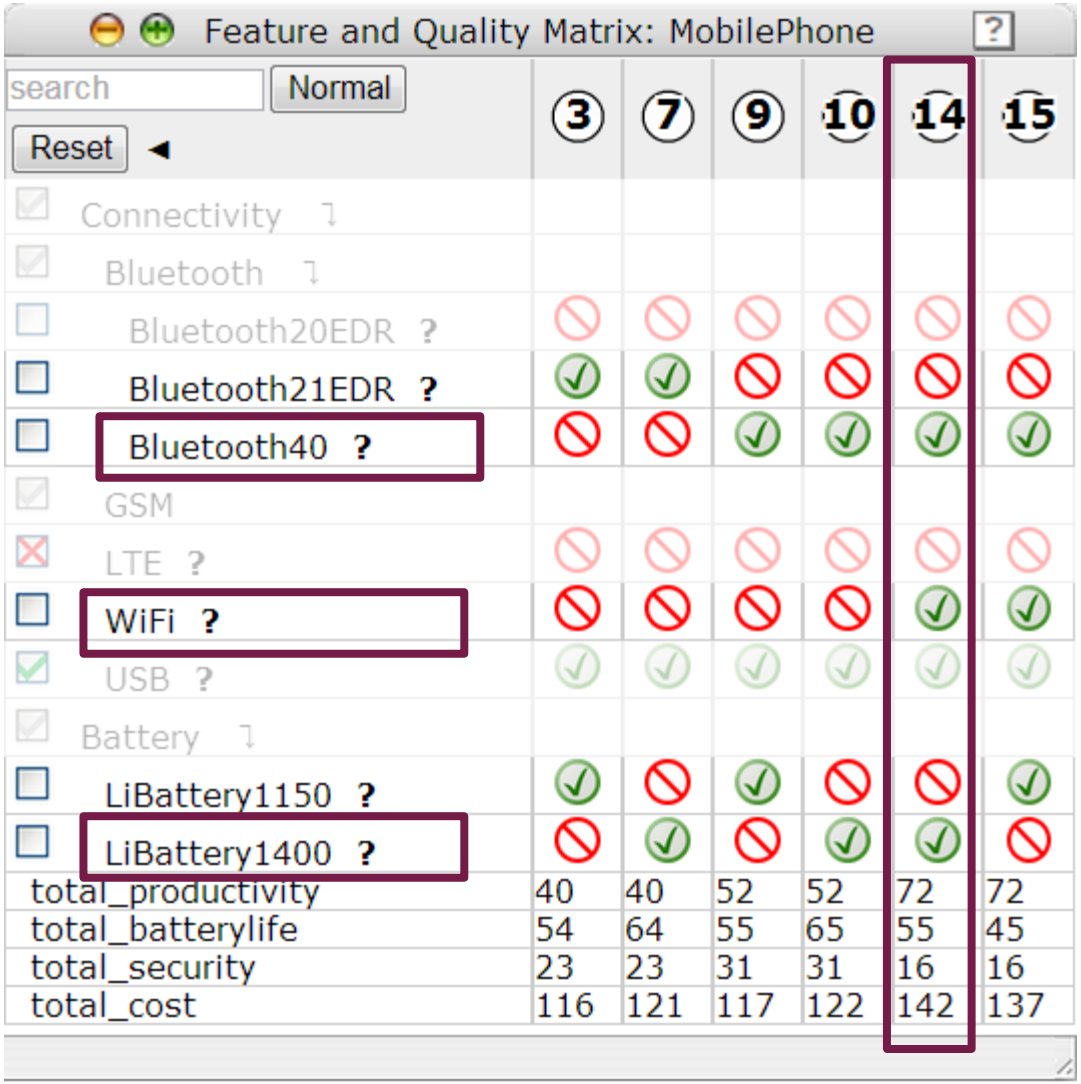
2.3 See Cumulative Impact

Feature and Quality Matrix: MobilePhone

search | Normal | Reset

	3	7	9	10	14	15
Connectivity						
Bluetooth						
Bluetooth20EDR ?	⊘	⊘	⊘	⊘	⊘	⊘
Bluetooth21EDR ?	✓	✓	⊘	⊘	⊘	⊘
Bluetooth40 ?	⊘	⊘	✓	✓	✓	✓
GSM						
LTE ?	⊘	⊘	⊘	⊘	⊘	⊘
WiFi ?	⊘	⊘	⊘	⊘	✓	✓
USB ?	✓	✓	✓	✓	✓	✓
Battery						
LiBattery1150 ?	✓	⊘	✓	⊘	⊘	✓
LiBattery1400 ?	⊘	✓	⊘	✓	✓	⊘
total_productivity	40	40	52	52	72	72
total_batterylife	54	64	55	65	55	45
total_security	23	23	31	31	16	16
total_cost	116	121	117	122	142	137

2.3 See Cumulative Impact



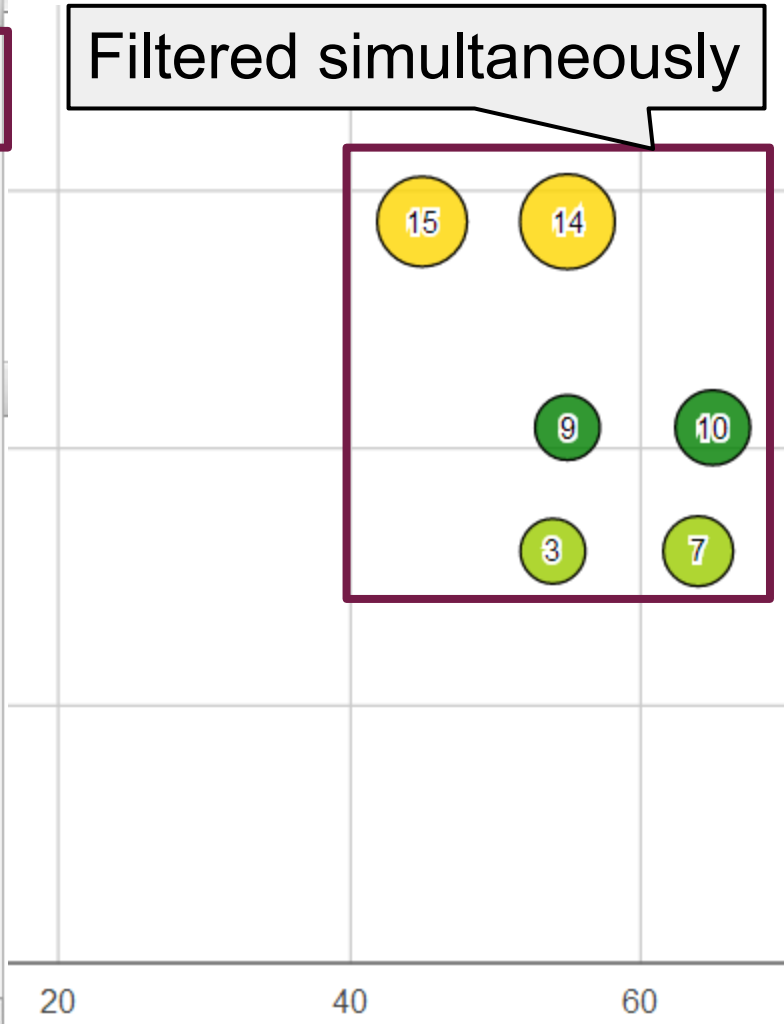
Wifi, Bluetooth 4.0, and **Battery 1400** give highest cost and productivity

2.4 Choose Desired Variants

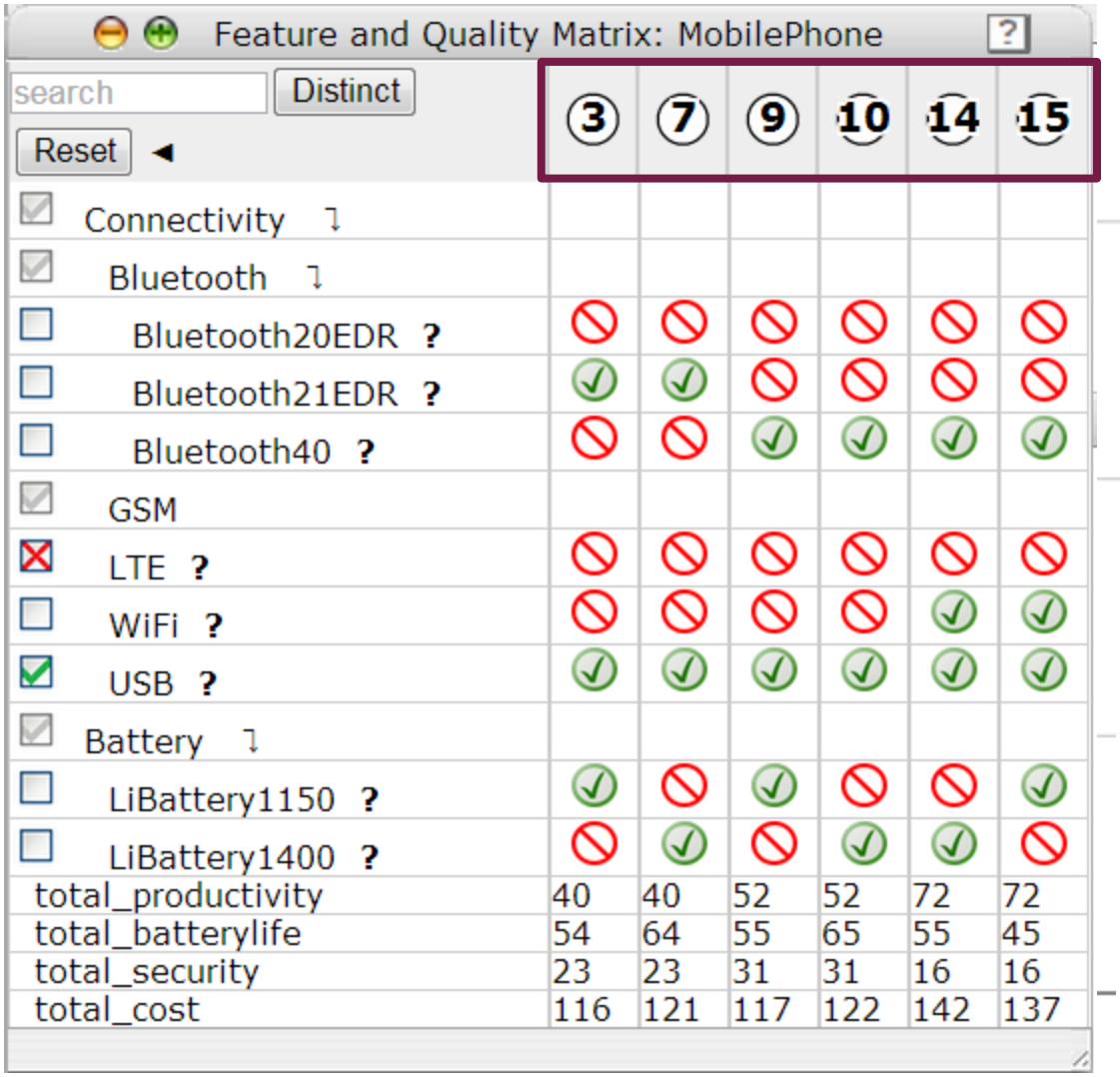
Feature and Quality Matrix: MobilePhone

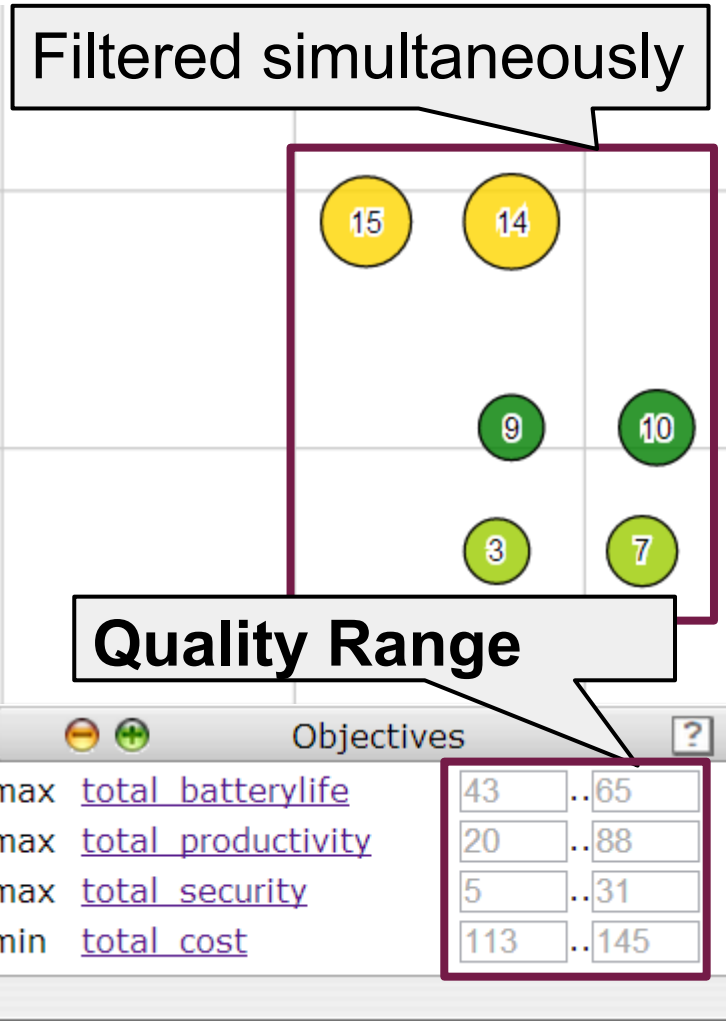
search | Distinct | Reset

		3	7	9	10	14	15
☑	Connectivity						
☑	Bluetooth						
☐	Bluetooth20EDR ?	⊘	⊘	⊘	⊘	⊘	⊘
☐	Bluetooth21EDR ?	✓	✓	⊘	⊘	⊘	⊘
☐	Bluetooth40 ?	⊘	⊘	✓	✓	✓	✓
☑	GSM						
☒	LTE ?	⊘	⊘	⊘	⊘	⊘	⊘
☐	WiFi ?	⊘	⊘	⊘	⊘	✓	✓
☑	USB ?	✓	✓	✓	✓	✓	✓
☑	Battery						
☐	LiBattery1150 ?	✓	⊘	✓	⊘	⊘	✓
☐	LiBattery1400 ?	⊘	✓	⊘	✓	✓	⊘
	total_productivity	40	40	52	52	72	72
	total_batterylife	54	64	55	65	55	45
	total_security	23	23	31	31	16	16
	total_cost	116	121	117	122	142	137

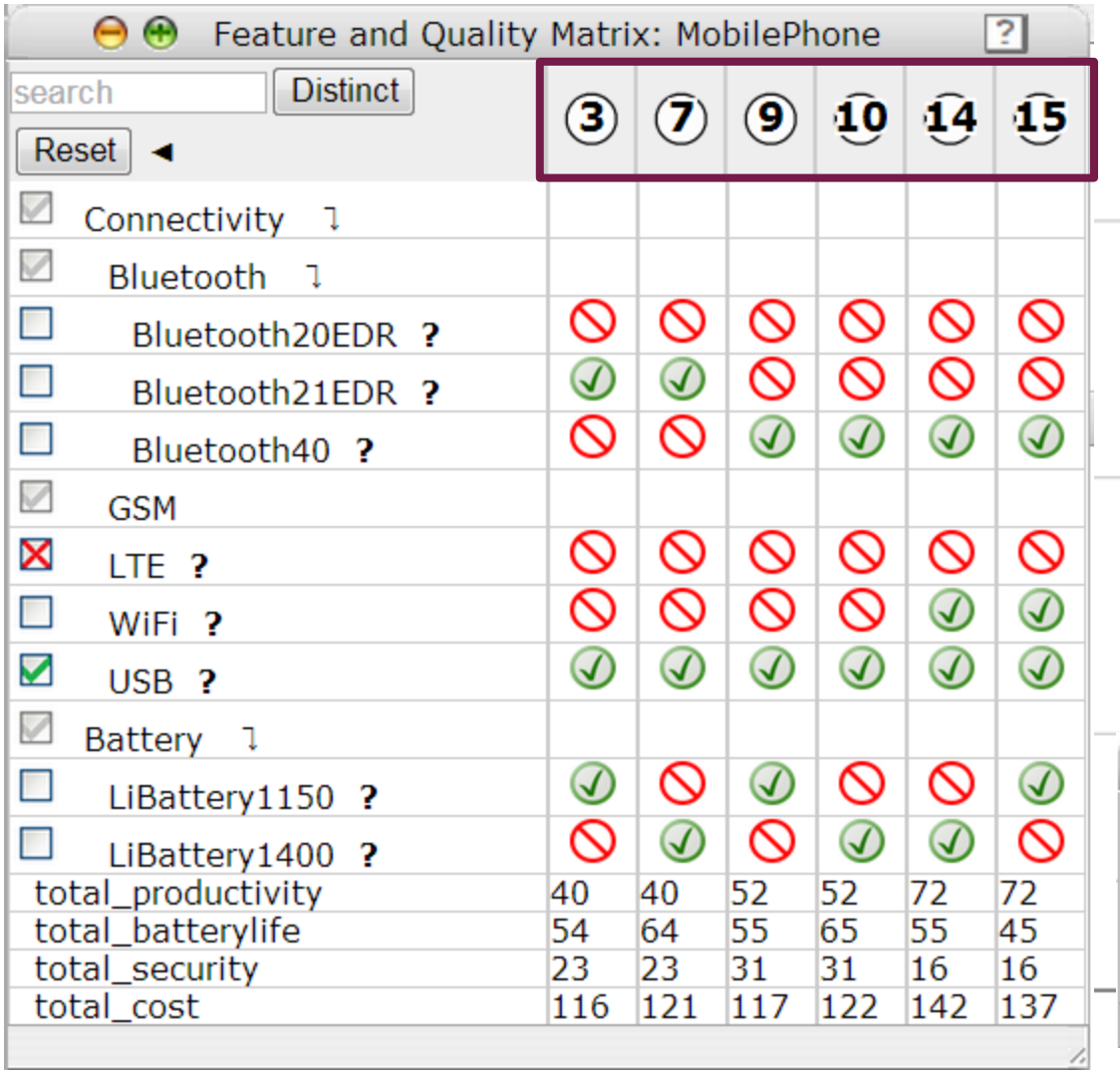


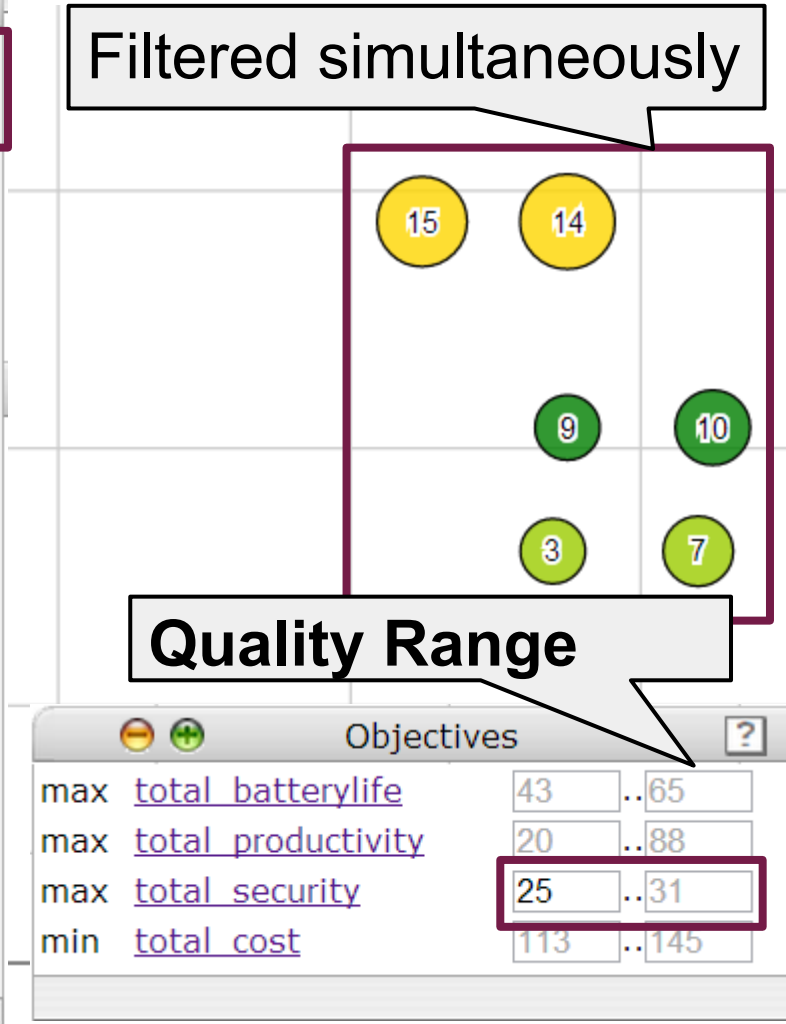
2.4 Choose Desired Variants



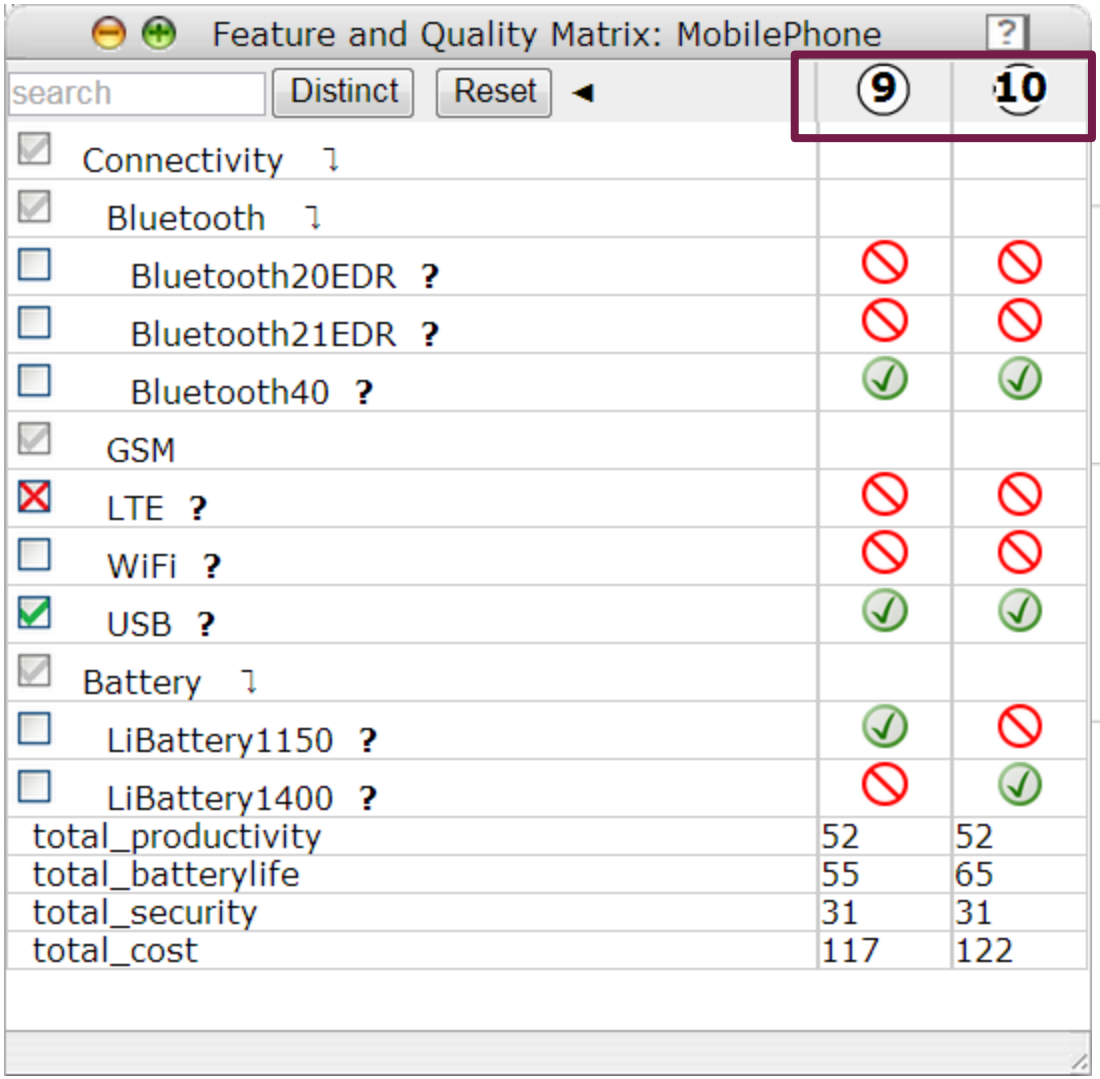


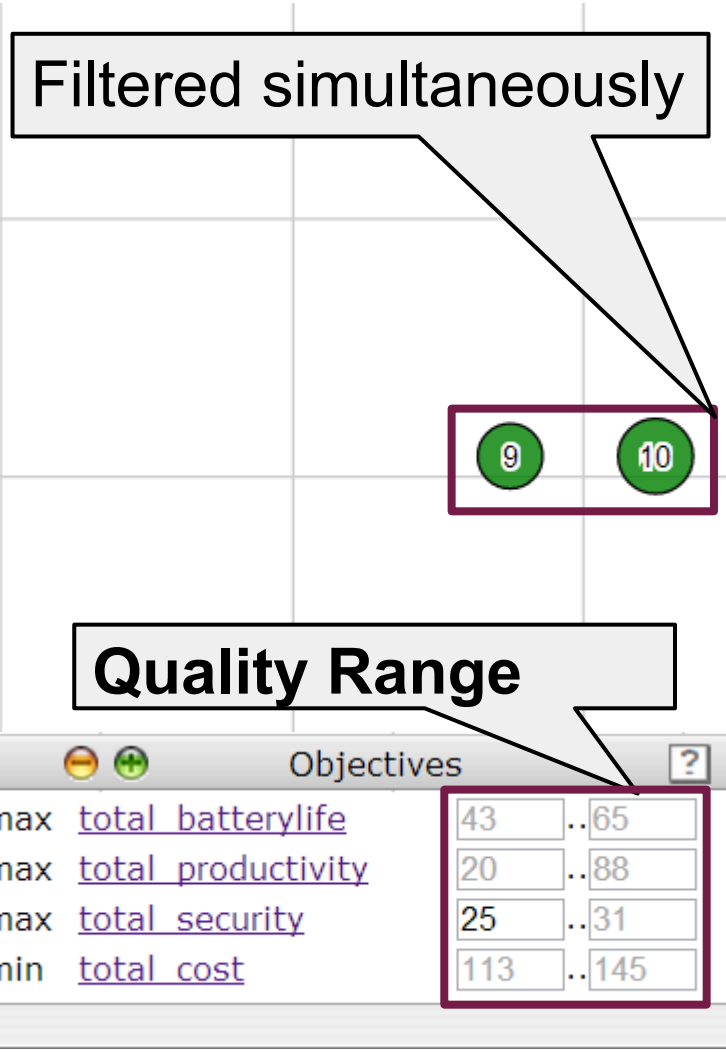
2.4 Choose Desired Variants



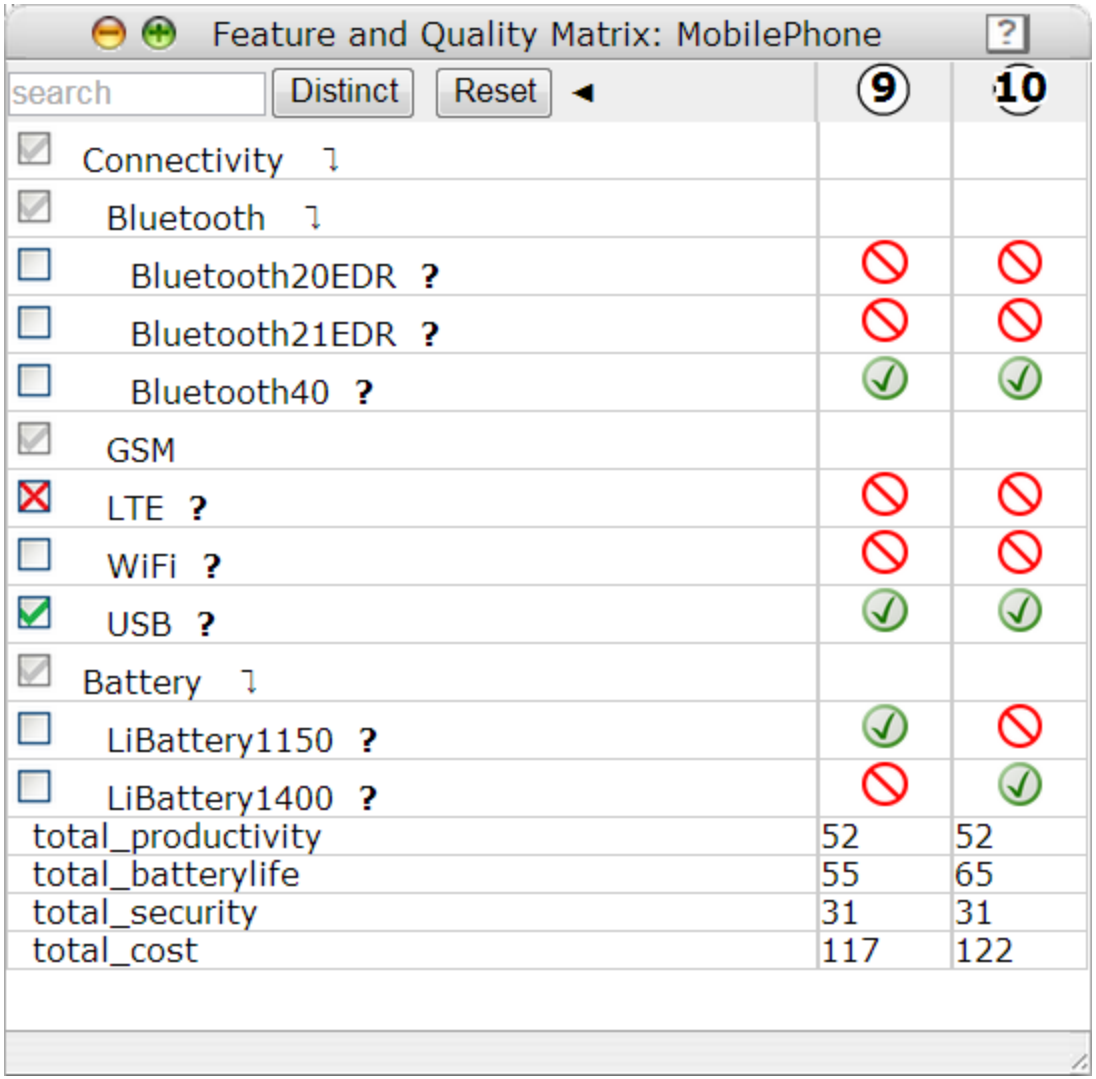


2.4 Choose Desired Variants

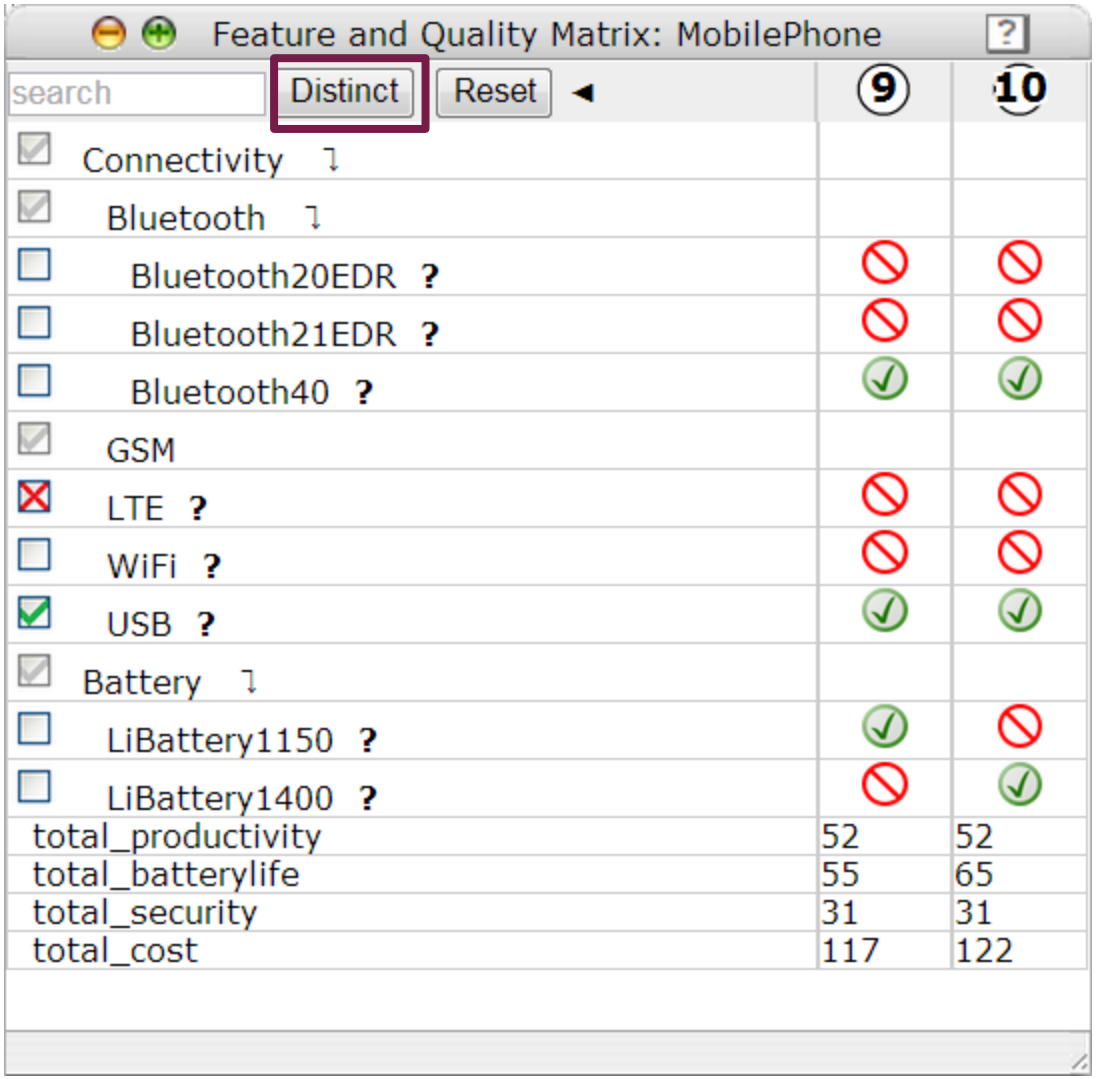




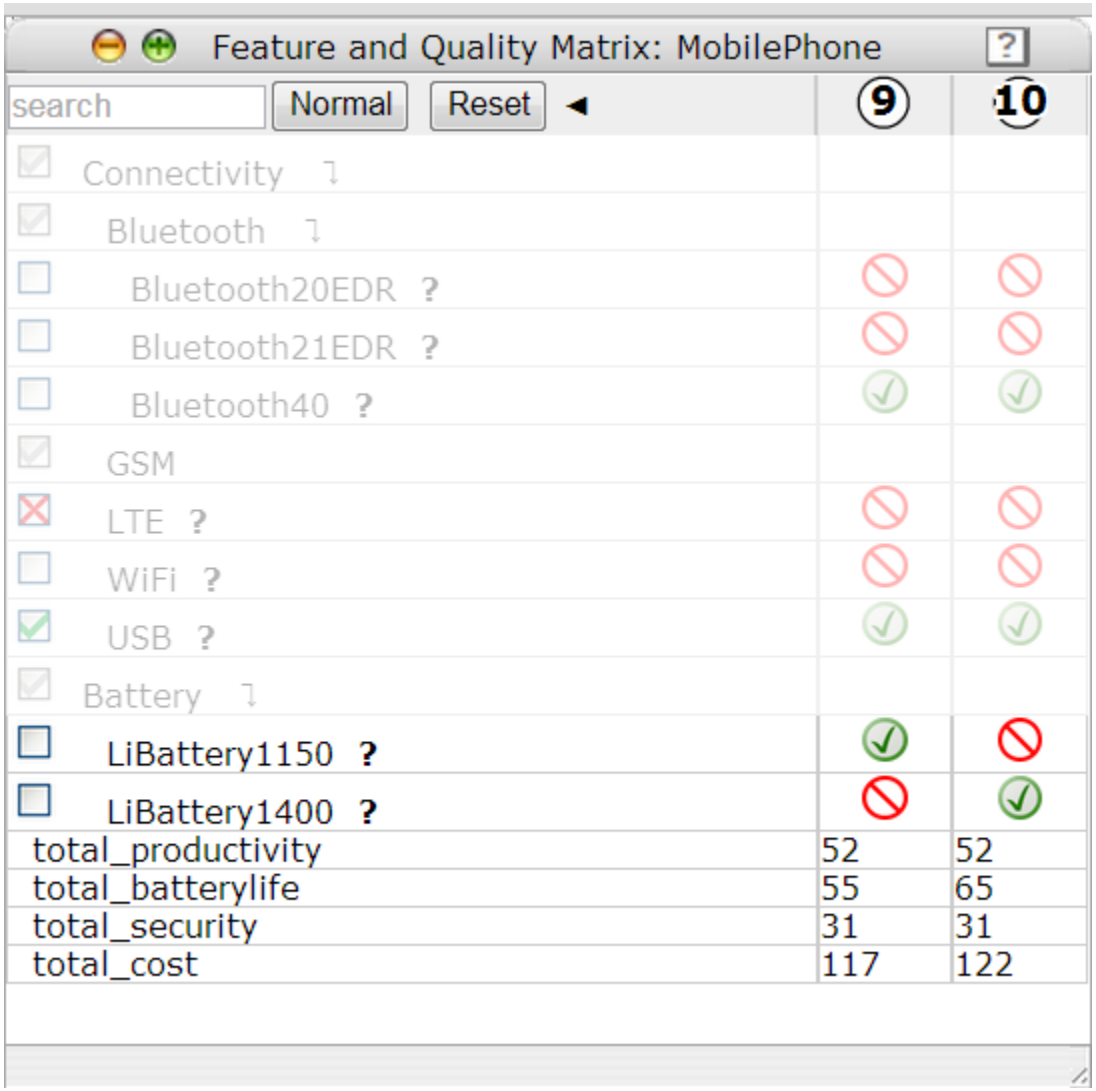
2.4 Choose Desired Variants



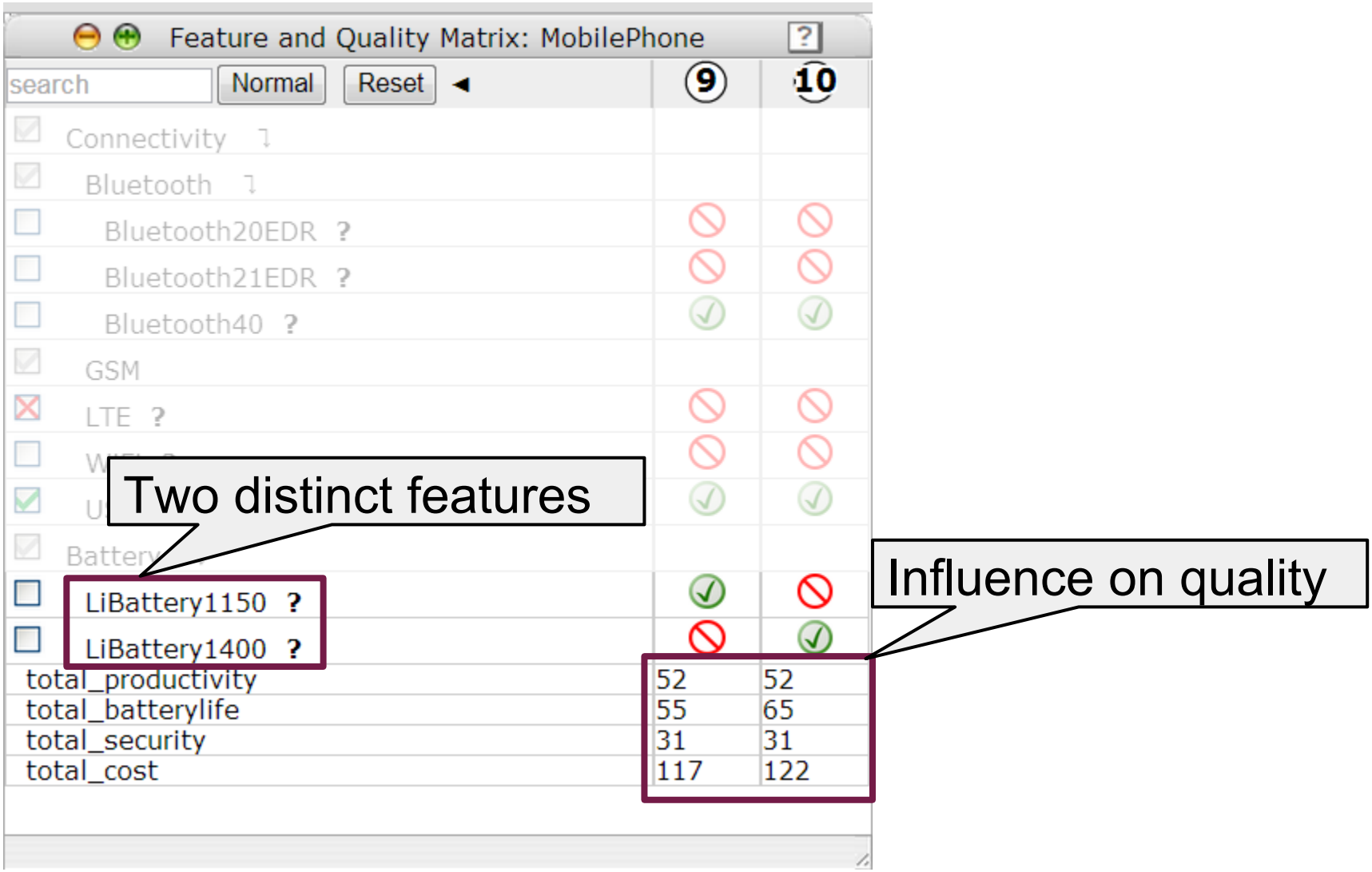
2.4 Choose Desired Variants



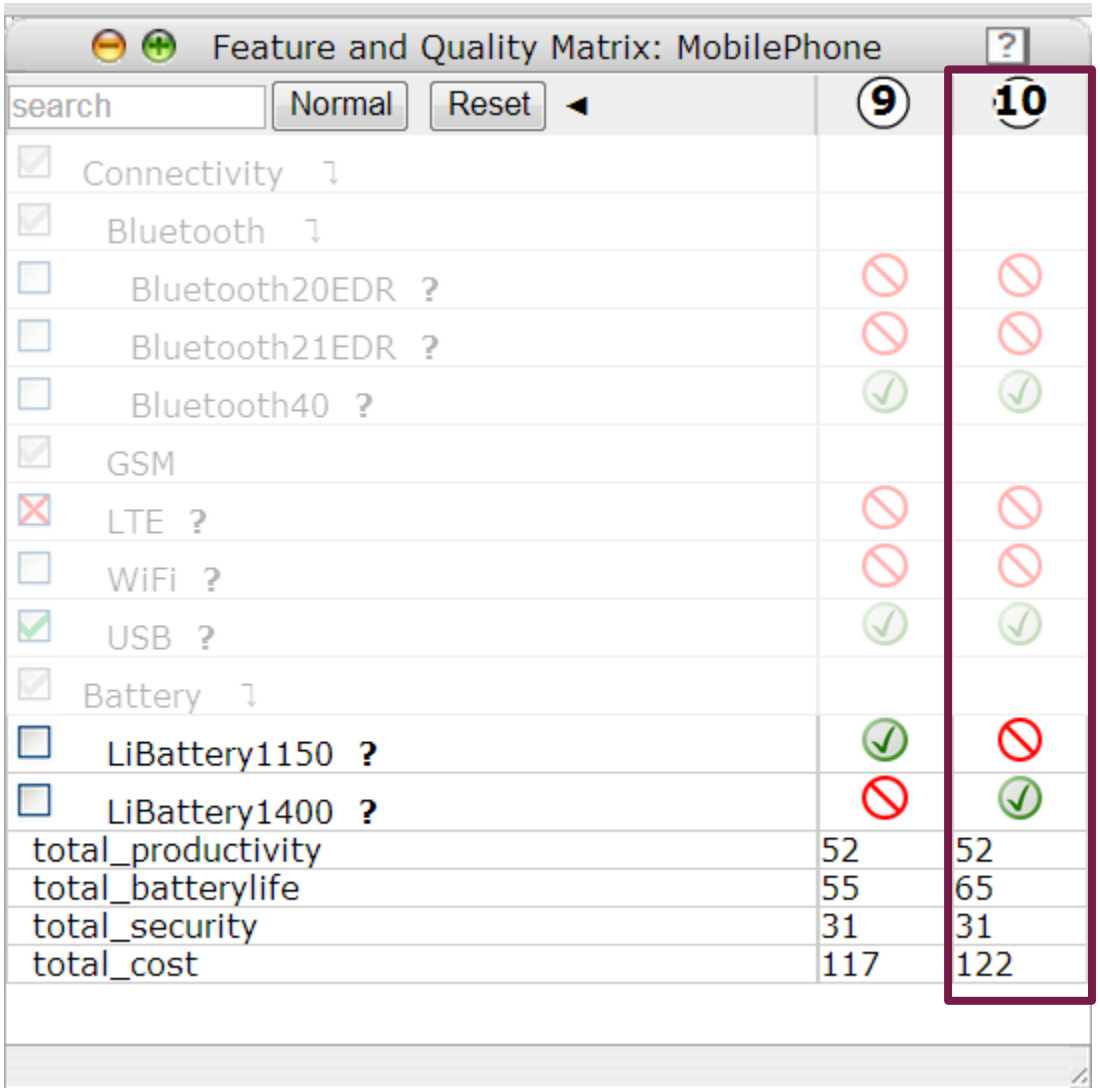
2.4 Choose Desired Variants



2.4 Choose Desired Variants



2.4 Choose Desired Variants



Chosen Variant 10, since it has a more desired **battery life**

2.4 Choose Desired Variants

Feature and Quality Matrix: MobilePhone

search | Normal | Reset

	9	10
Connectivity		
Bluetooth		
Bluetooth20EDR ?	⊘	⊘
Bluetooth21EDR ?	⊘	⊘
Bluetooth40 ?	✓	✓
GSM		
LTE ?	⊘	⊘
WiFi ?	⊘	⊘
USB ?	✓	✓
Battery		
LiBattery1150 ?	✓	⊘
LiBattery1400 ?	⊘	✓
total_productivity	52	52
total_batterylife	55	65
total_security	31	31
total_cost	117	122

Chosen Variant 10, since it has a more desired **battery life**

Use Cases (2)

2.1 See feature **occurrences**: is `USB` frequent or rare?

2.2 Get variants **by features**: with `WiFi`, without `LTE`?

2.3 See **cumulative impact** on quality: `USB + LTE`?

2.4 Choose **desired** variants by features and quality?

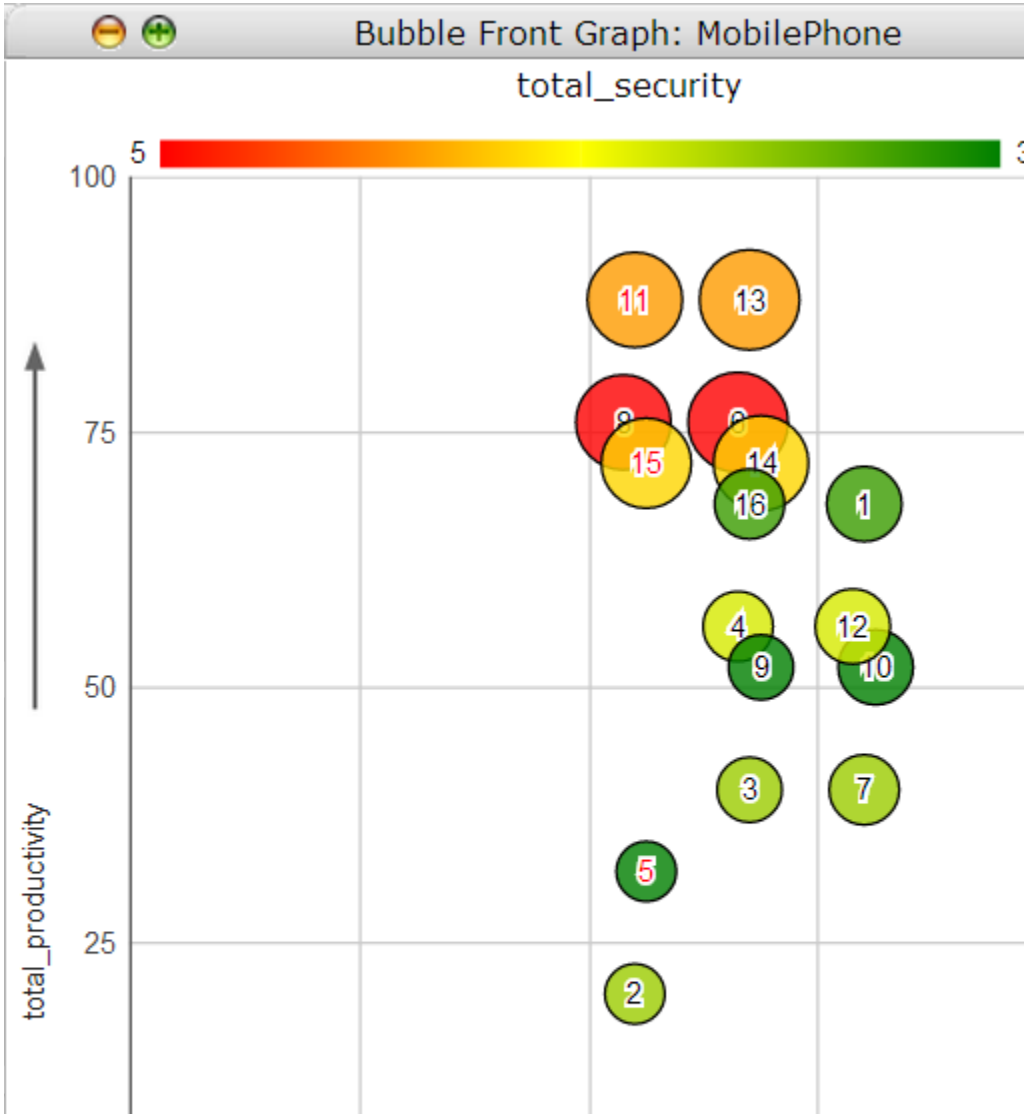
Use Cases (3)

3.1 Explore variants **individually**?

3.2 Select variants with a **similar** features?

3.3 Observe **evolution** of optimal variants?

3.1 Explore Variants Individually



3.1 Explore Variants Individually

3.1 Explore Variants Individually

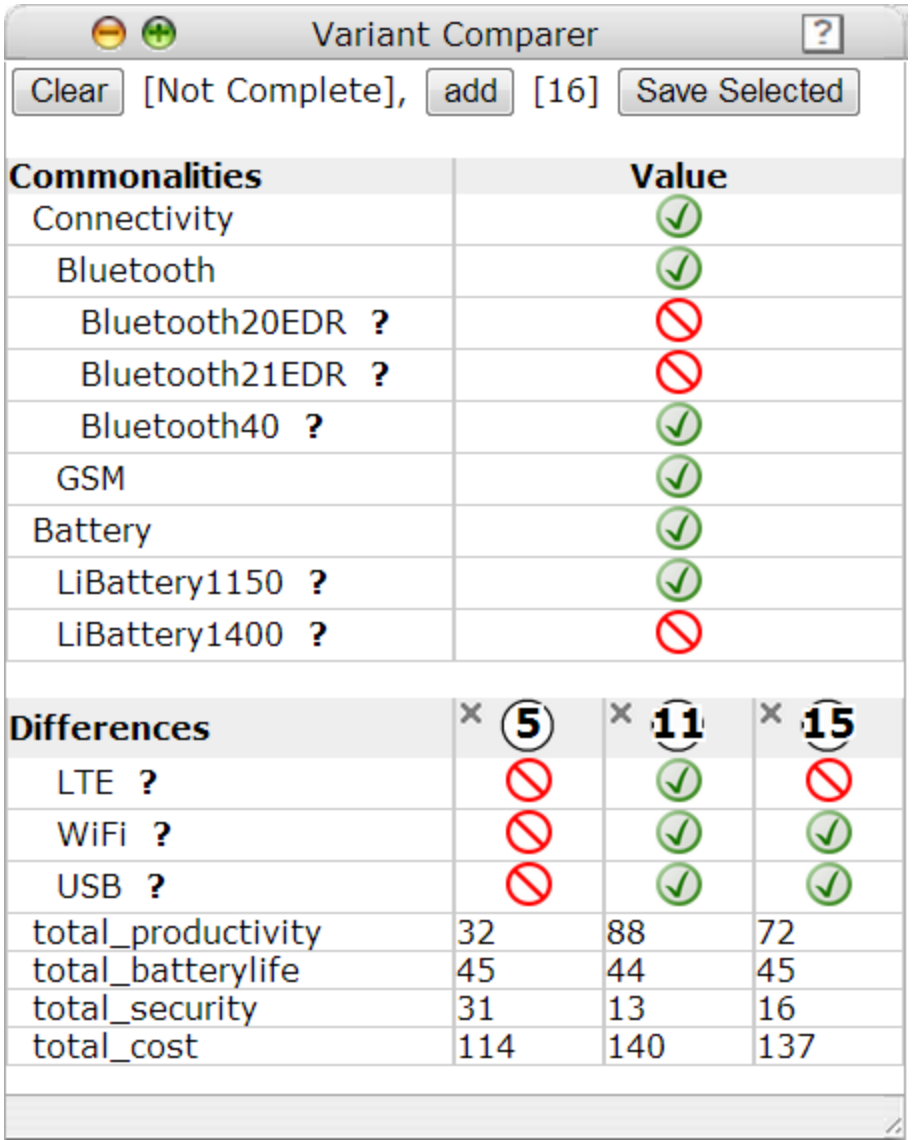
Variant Comparer

Clear [Not Complete], add [16] Save Selected

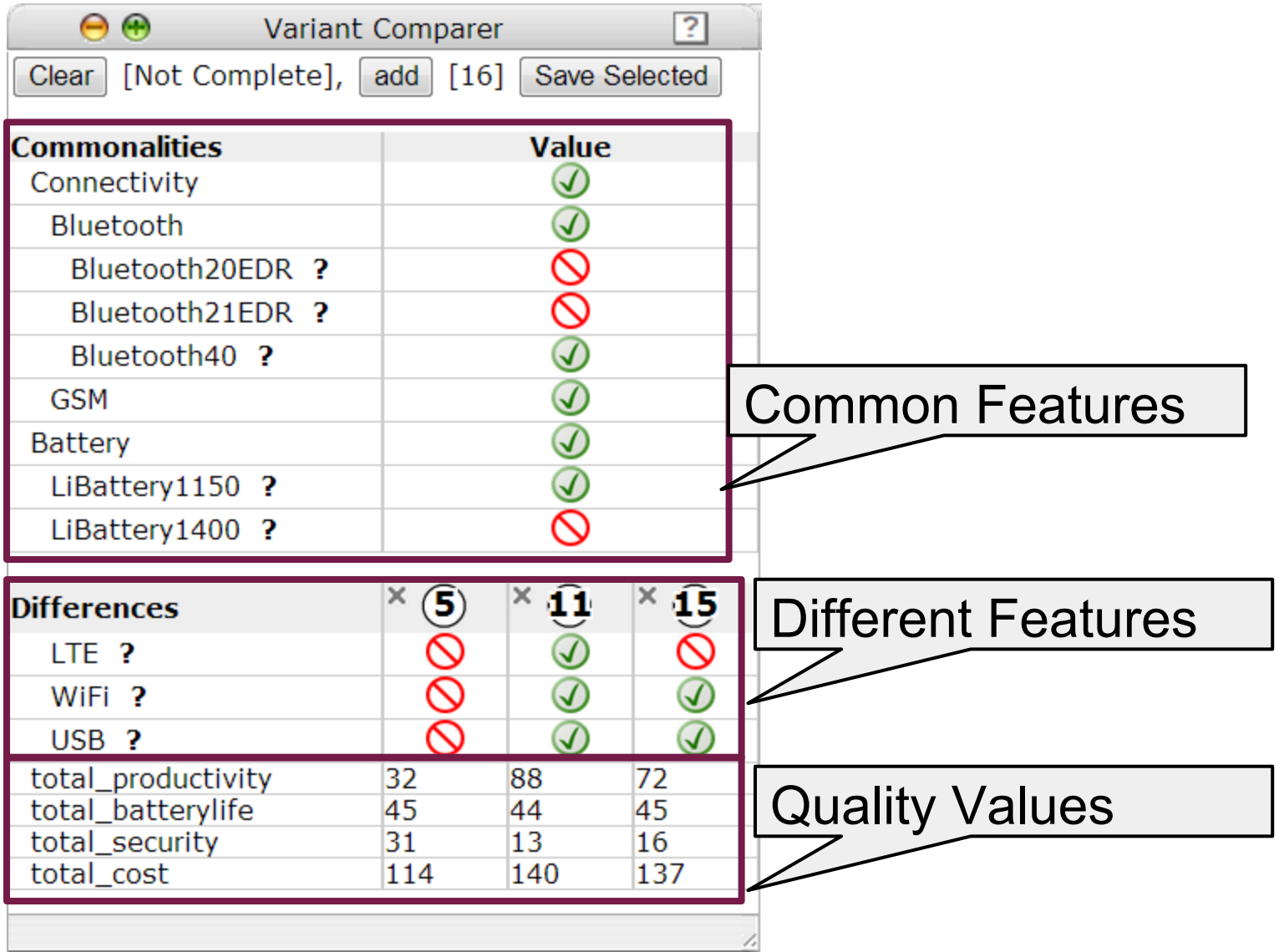
Commonalities	Value
Connectivity	✓
Bluetooth	✓
Bluetooth20EDR ?	⊘
Bluetooth21EDR ?	⊘
Bluetooth40 ?	✓
GSM	✓
Battery	✓
LiBattery1150 ?	✓
LiBattery1400 ?	⊘

Differences	× 5	× 11	× 15
LTE ?	⊘	✓	⊘
WiFi ?	⊘	✓	✓
USB ?	⊘	✓	✓
total_productivity	32	88	72
total_batterylife	45	44	45
total_security	31	13	16
total_cost	114	140	137

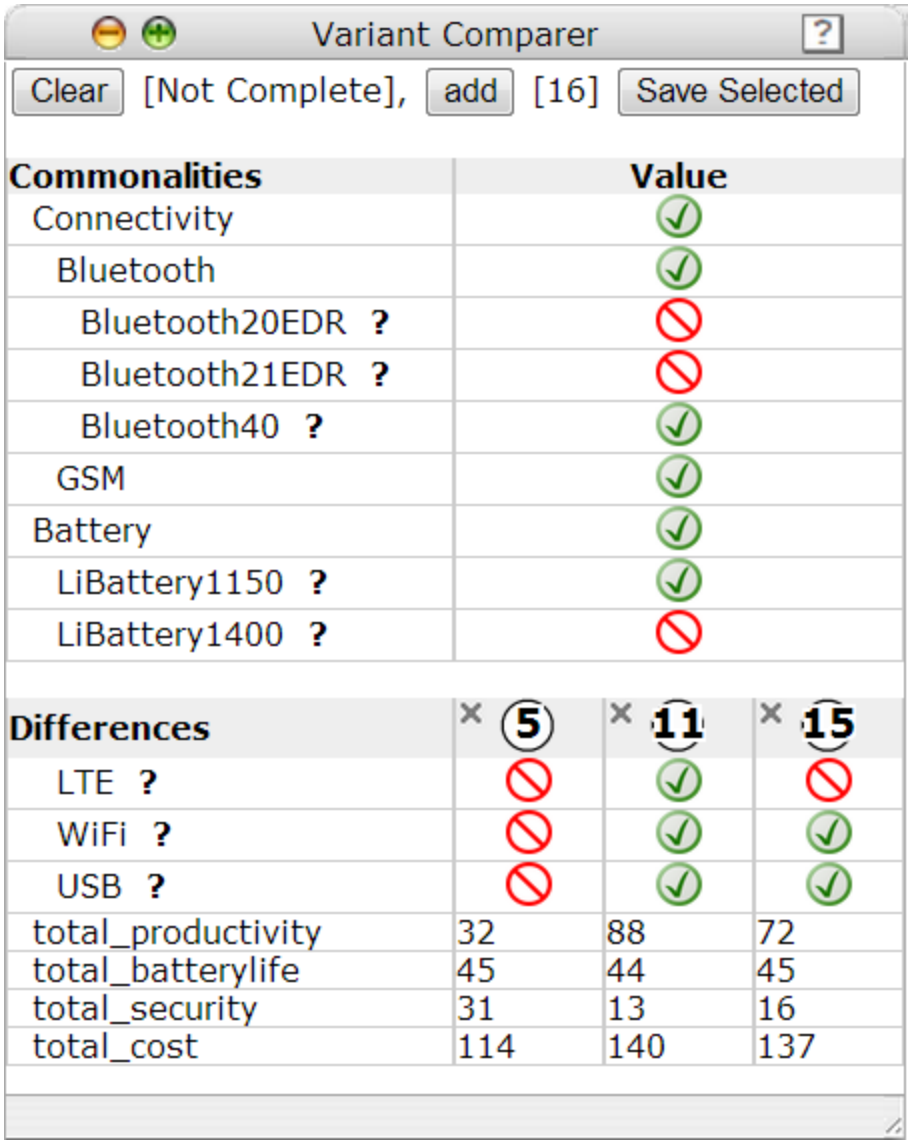
Variant Comparer



Variant Comparer



3.2 Variants With Similar Features



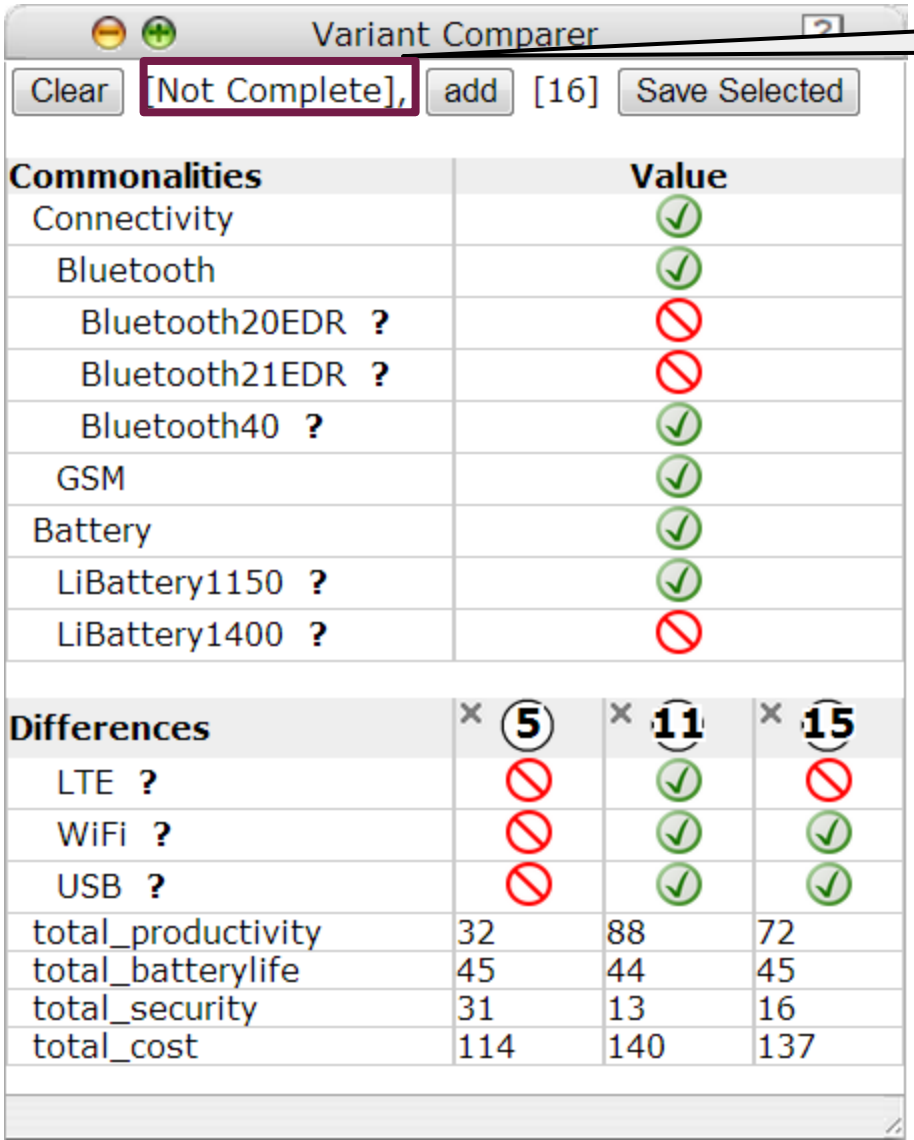
Variant Comparer

Clear [Not Complete], add [16] Save Selected

Commonalities	Value
Connectivity	✓
Bluetooth	✓
Bluetooth20EDR ?	✗
Bluetooth21EDR ?	✗
Bluetooth40 ?	✓
GSM	✓
Battery	✓
LiBattery1150 ?	✓
LiBattery1400 ?	✗

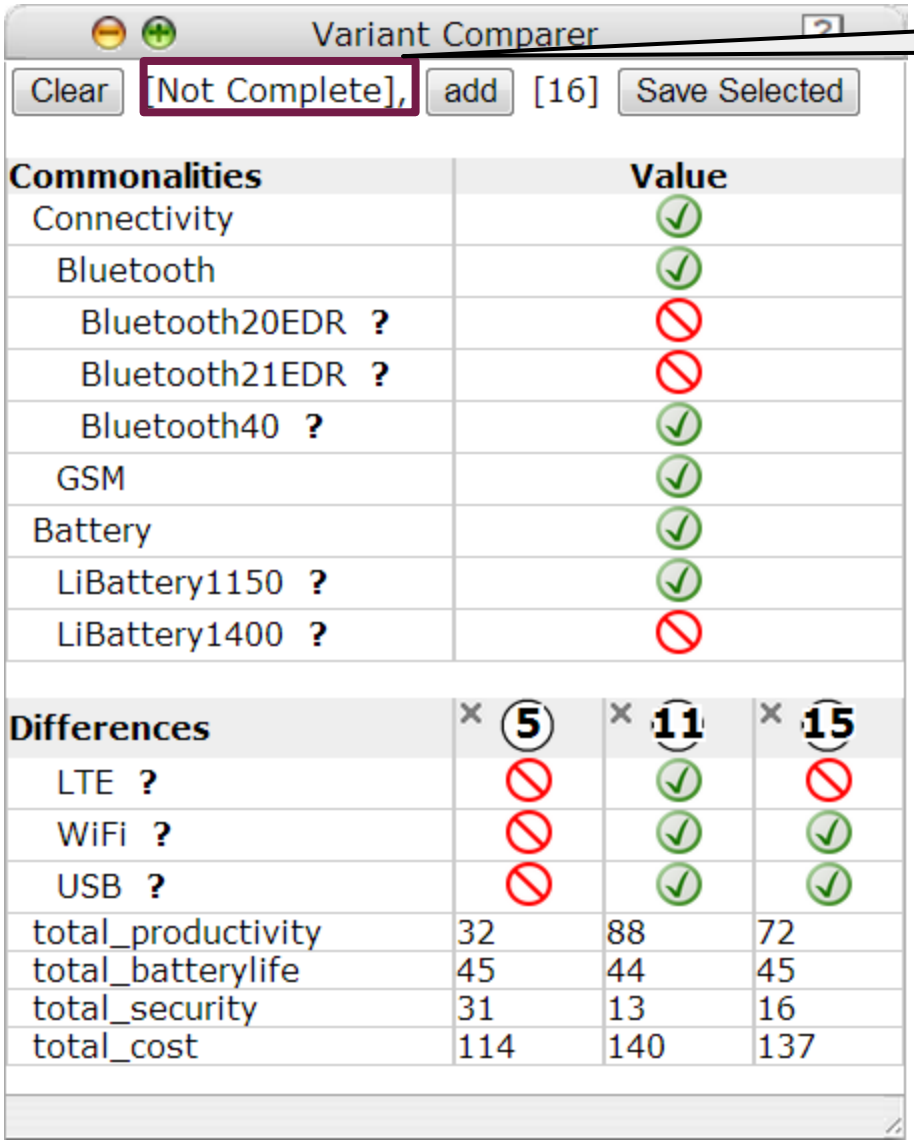
Differences	× 5	× 11	× 15
LTE ?	✗	✓	✗
WiFi ?	✗	✓	✓
USB ?	✗	✓	✓
total_productivity	32	88	72
total_batterylife	45	44	45
total_security	31	13	16
total_cost	114	140	137

3.2 Variants With Similar Features



Completeness of the set

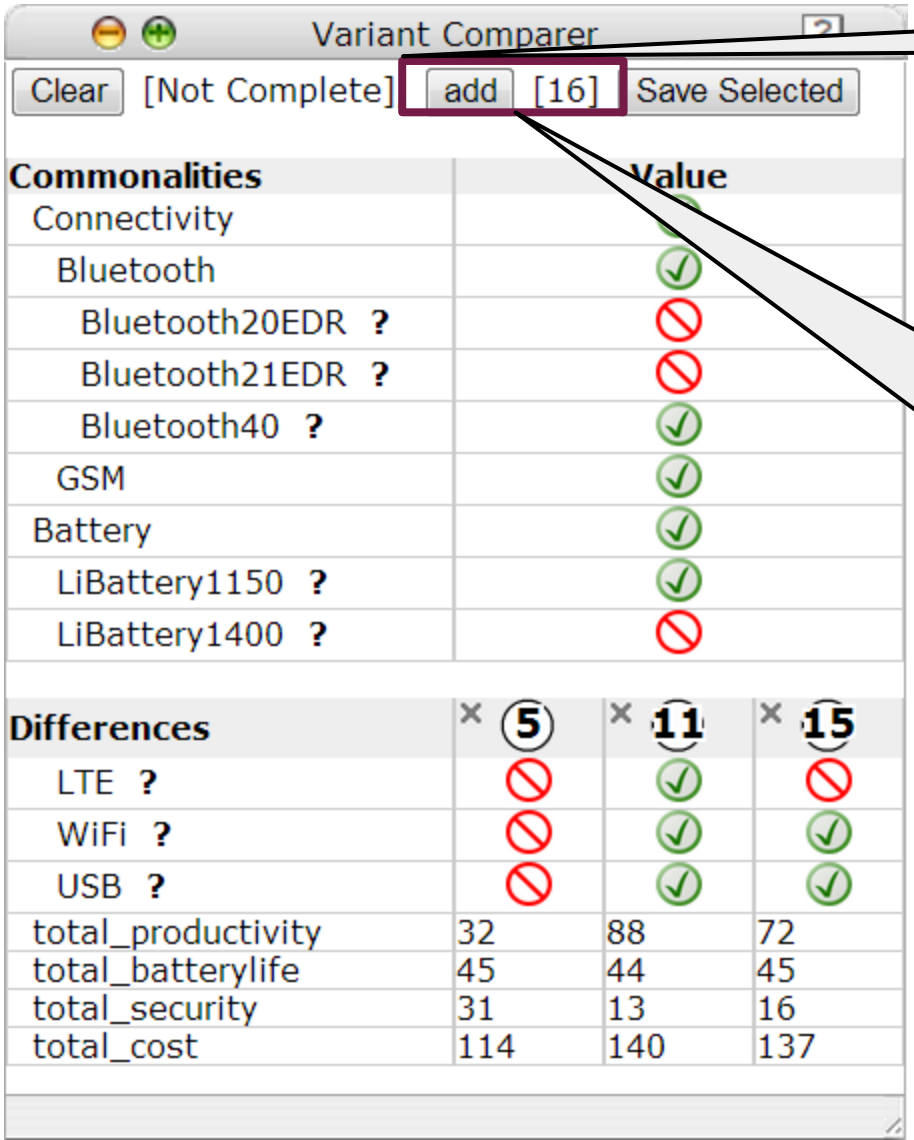
3.2 Variants With Similar Features



Completeness of the set

A set is complete if any added variant will decrease commonality

3.2 Variants With Similar Features

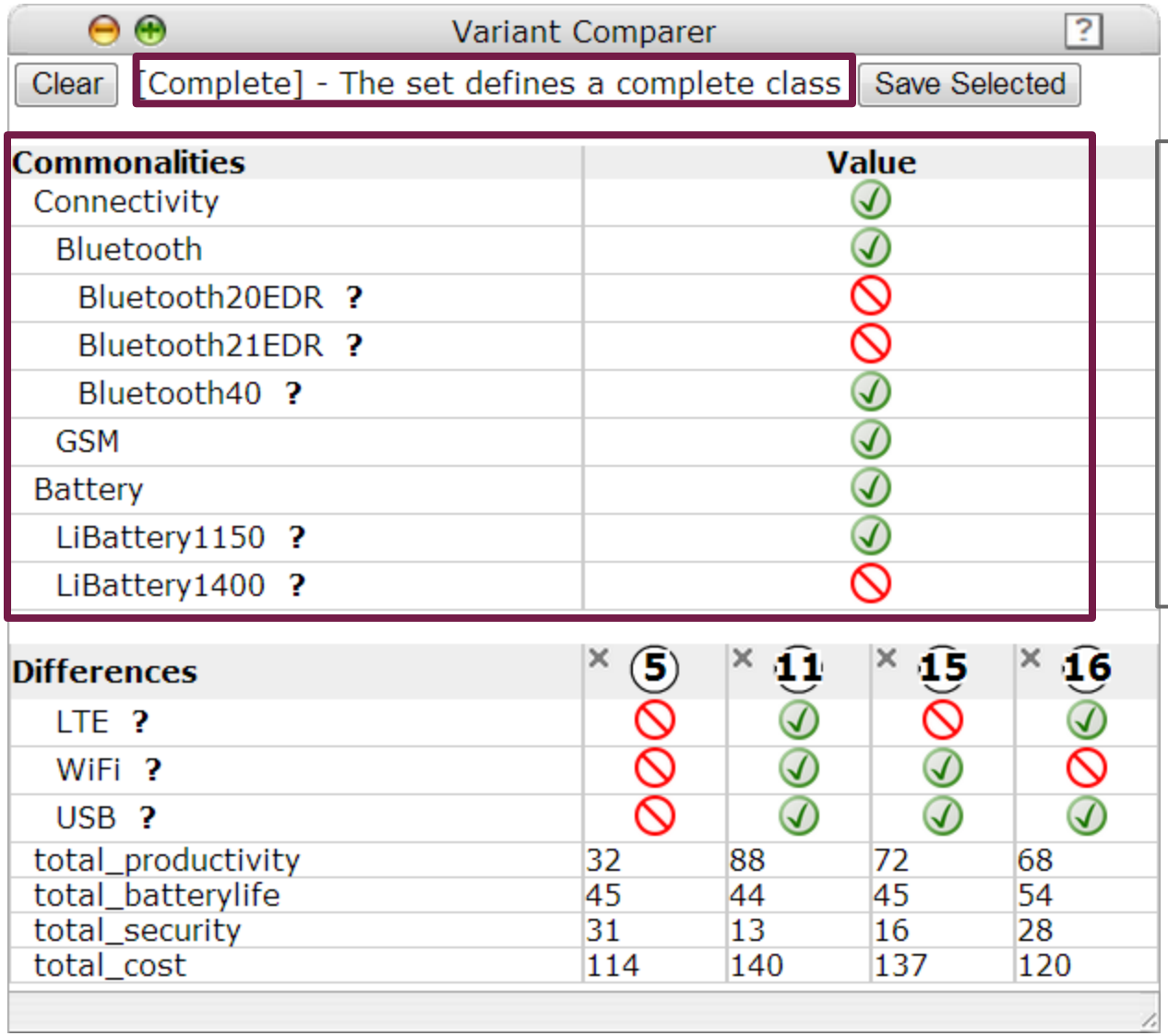


Completeness of the set

A set is complete if any added variant will decrease commonality

Include remaining varaints

3.2 Variants With Similar Features



All variants with **Bluetooth 4.0**, **GSM**, and **LiBattery1150**.

- a complete set

3.1 Explore Variants Individually: Eliminate Undesired Variants

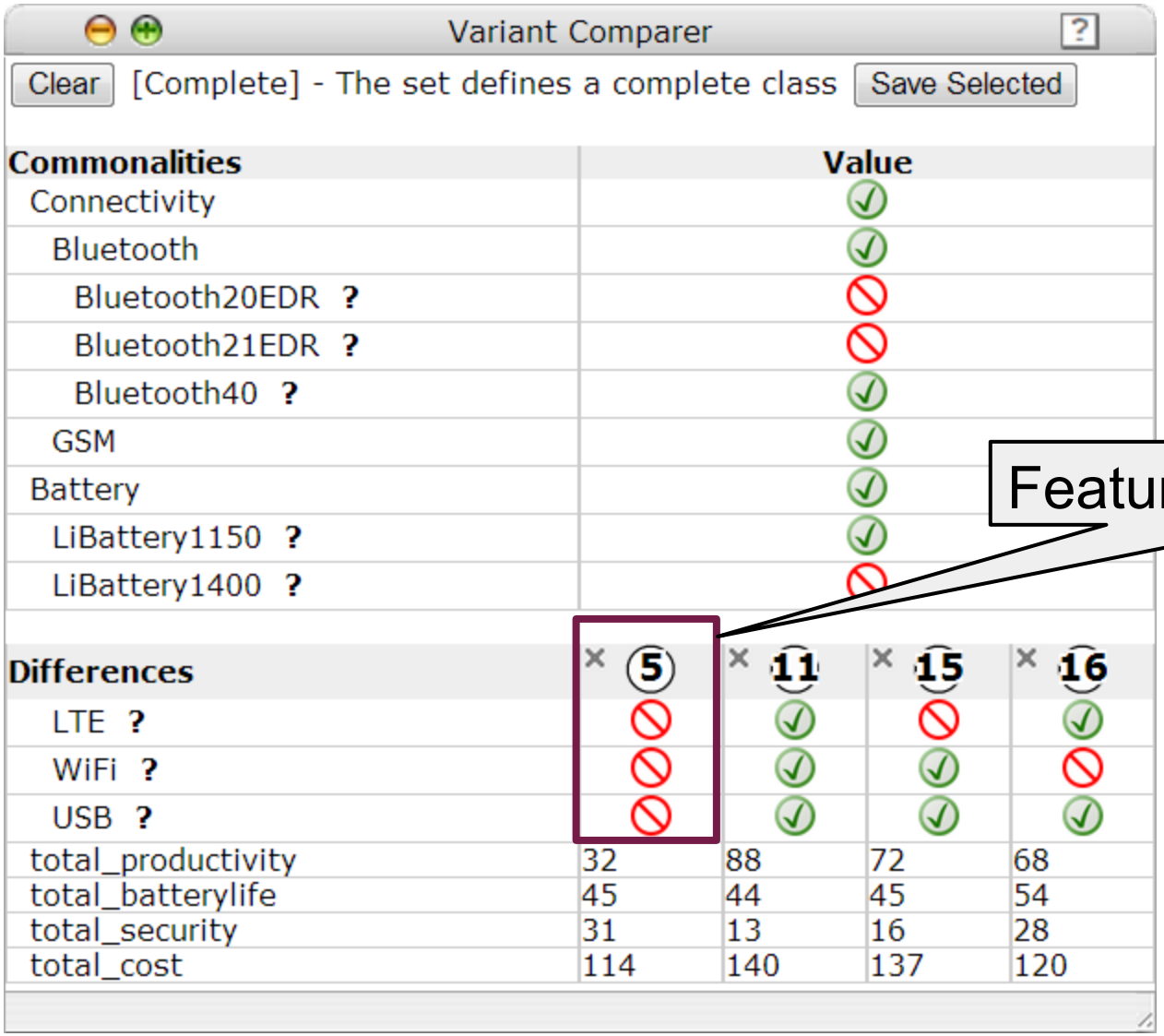
Variant Comparer

Clear [Complete] - The set defines a complete class Save Selected

Commonalities	Value
Connectivity	✓
Bluetooth	✓
Bluetooth20EDR ?	⊘
Bluetooth21EDR ?	⊘
Bluetooth40 ?	✓
GSM	✓
Battery	✓
LiBattery1150 ?	✓
LiBattery1400 ?	⊘

Differences	× 5	× 11	× 15	× 16
LTE ?	⊘	✓	⊘	✓
WiFi ?	⊘	✓	✓	⊘
USB ?	⊘	✓	✓	✓
total_productivity	32	88	72	68
total_batterylife	45	44	45	54
total_security	31	13	16	28
total_cost	114	140	137	120

3.1 Explore Variants Individually: Eliminate Undesired Variants



Features not supported

3.1 Explore Variants Individually: Eliminate Undesired Variants

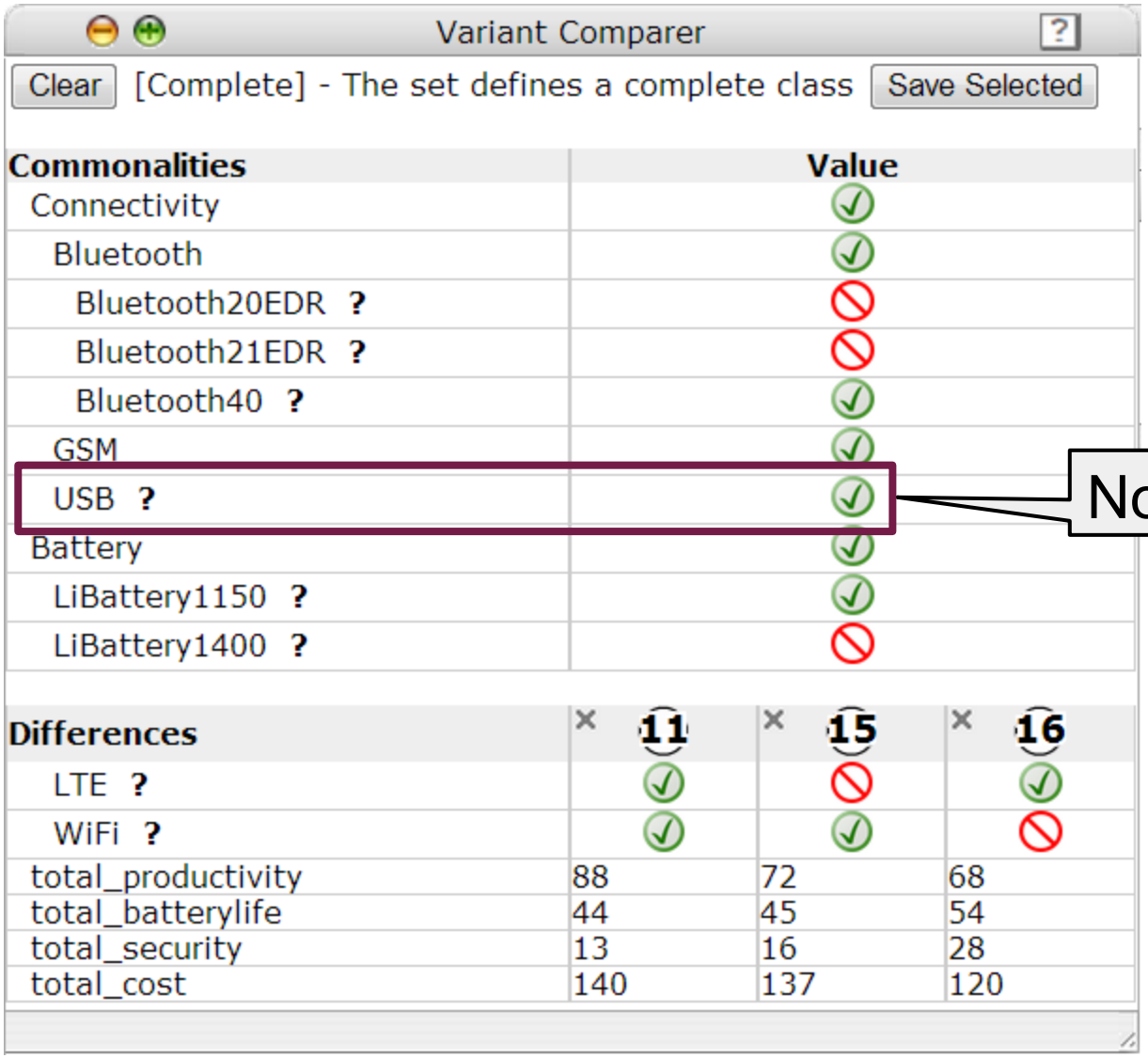
Variant Comparer

Clear [Complete] - The set defines a complete class Save Selected

Commonalities	Value			
Connectivity	✓			
Bluetooth	✓			
Bluetooth20EDR ?	⊘			
Bluetooth21EDR ?	⊘			
Bluetooth40 ?	✓			
GSM	✓			
Battery	✓			
LiBattery1150 ?	✓			
LiBattery1400 ?	⊘			
Differences	× 5	× 11	× 15	× 16
LTE ?	⊘	✓	⊘	✓
WiFi ?	⊘	✓	✓	⊘
USB ?	⊘	✓	✓	✓
total_productivity	32	88	72	68
total_batterylife	45	44	45	54
total_security	31	13	16	28
total_cost	114	140	137	120

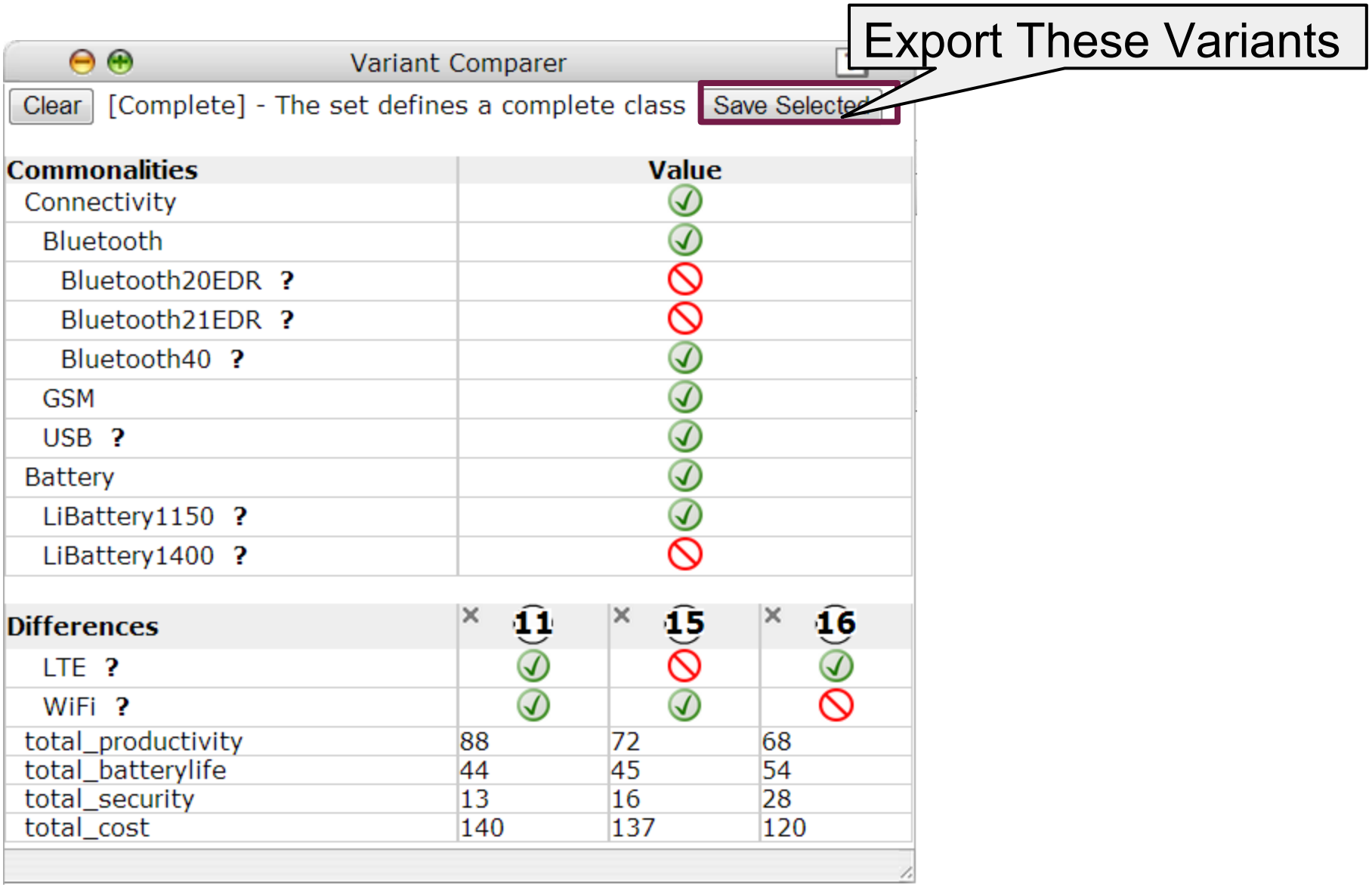
Exclude the variant

3.1 Explore Variants Individually



Now USB is common

3.1 Explore Variants Individually



3.1 Explore Variants Individually

Export These Variants

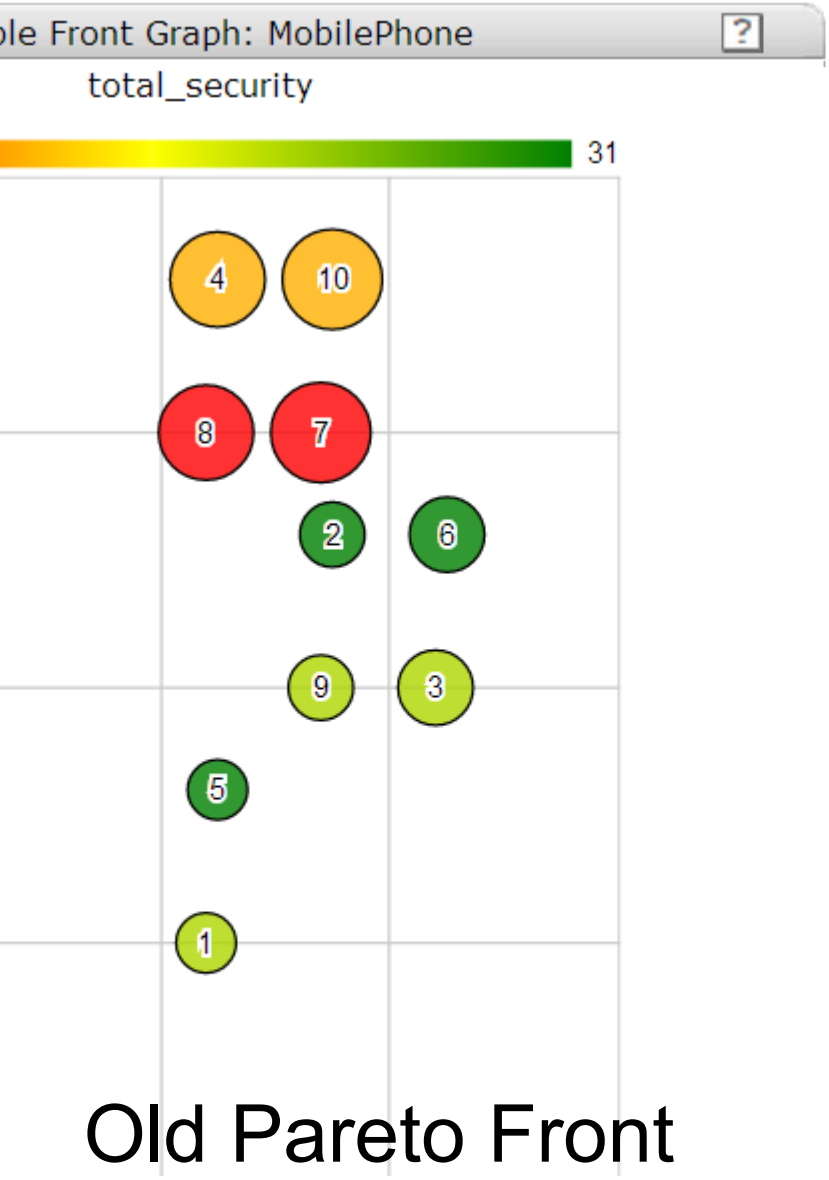
Variant Comparer

Clear [Complete] - The set defines a complete class Save Selected

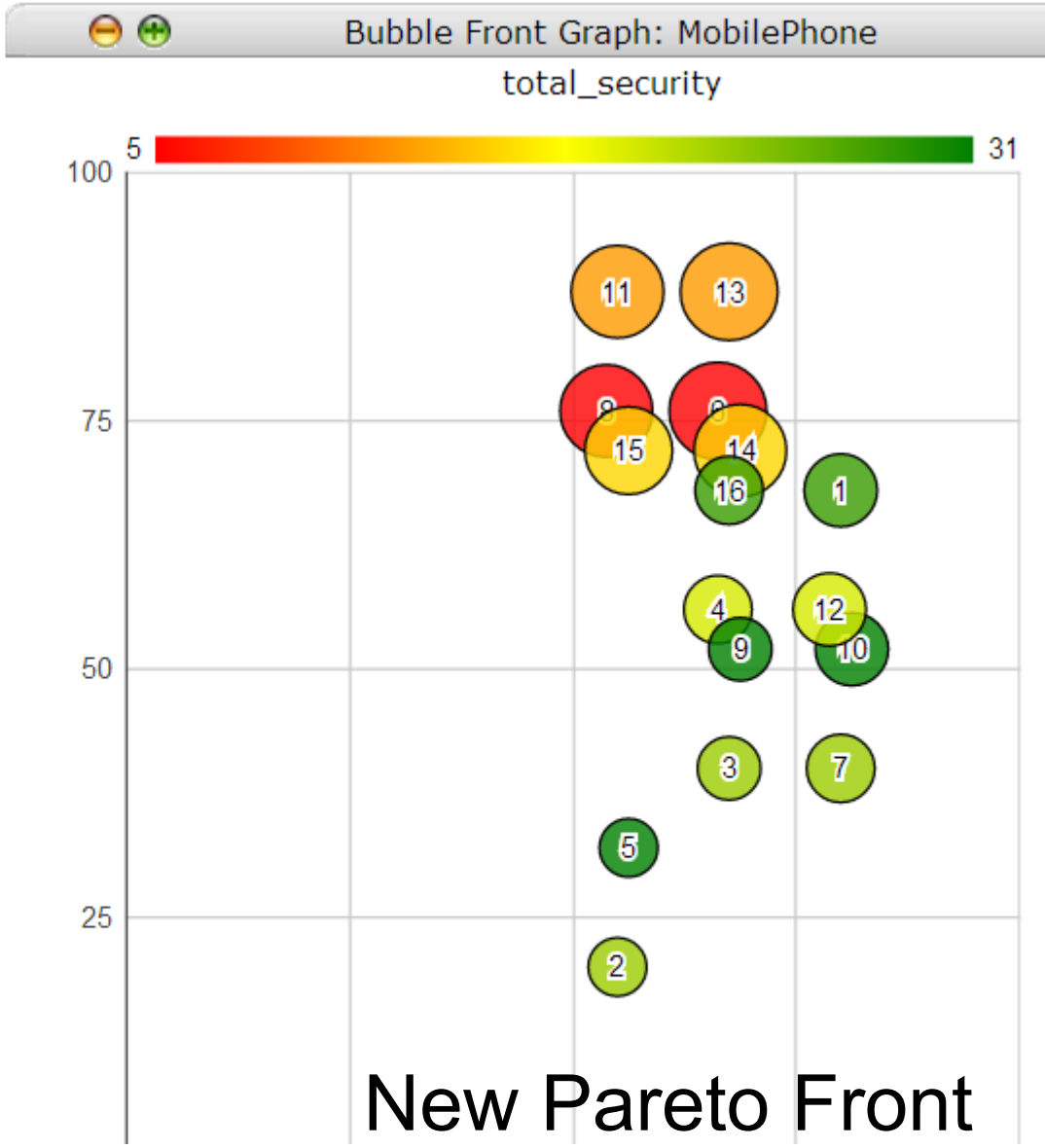
Commonalities	Value
Connectivity	✓
Bluetooth	✓
Bluetooth20EDR ?	✗
Bluetooth21EDR ?	✗
Bluetooth40 ?	✓
GSM	✓
USB ?	✓
Battery	✓
LiBattery1150 ?	✓
LiBattery1400 ?	✗

Differences	× 11	× 15	× 16
LTE ?	✓	✗	✓
WiFi ?	✓	✓	✗
total_productivity	88	72	68
total_batterylife	44	45	54
total_security	13	16	28
total_cost	140	137	120

Product Line Evolution

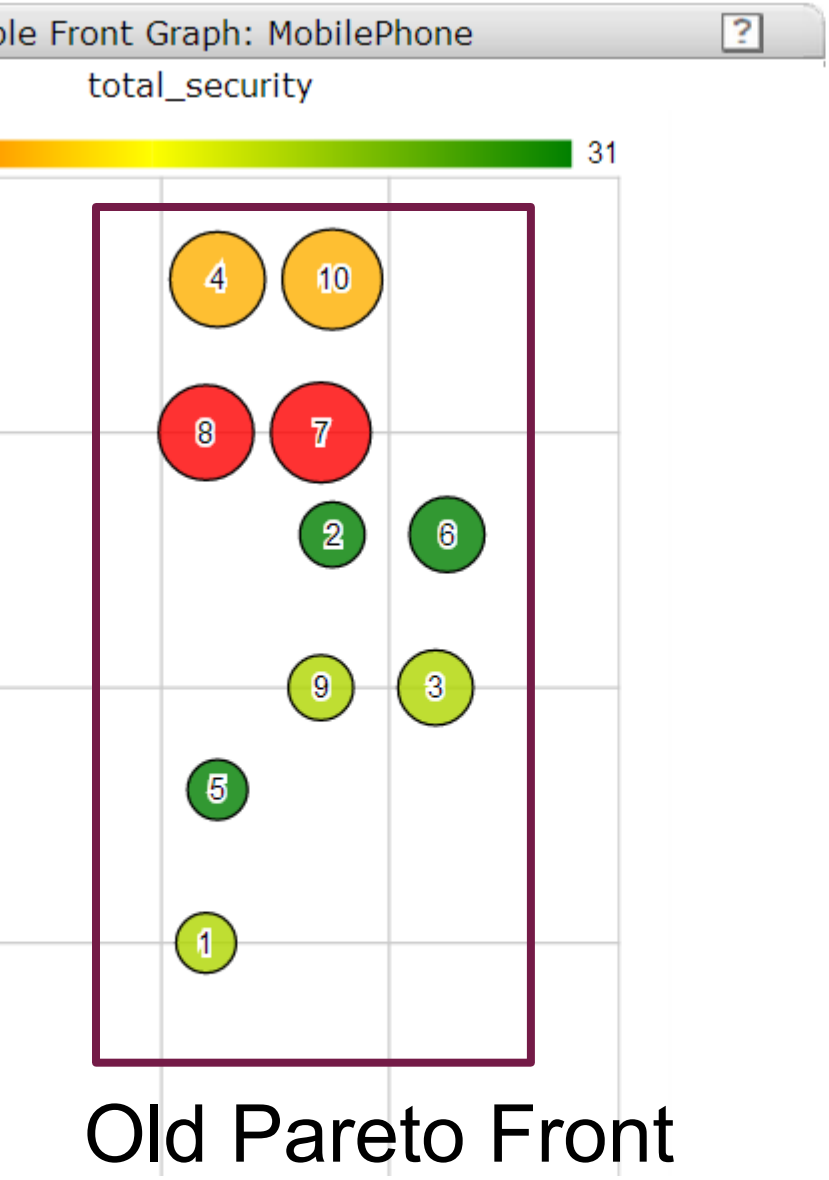


Old Pareto Front

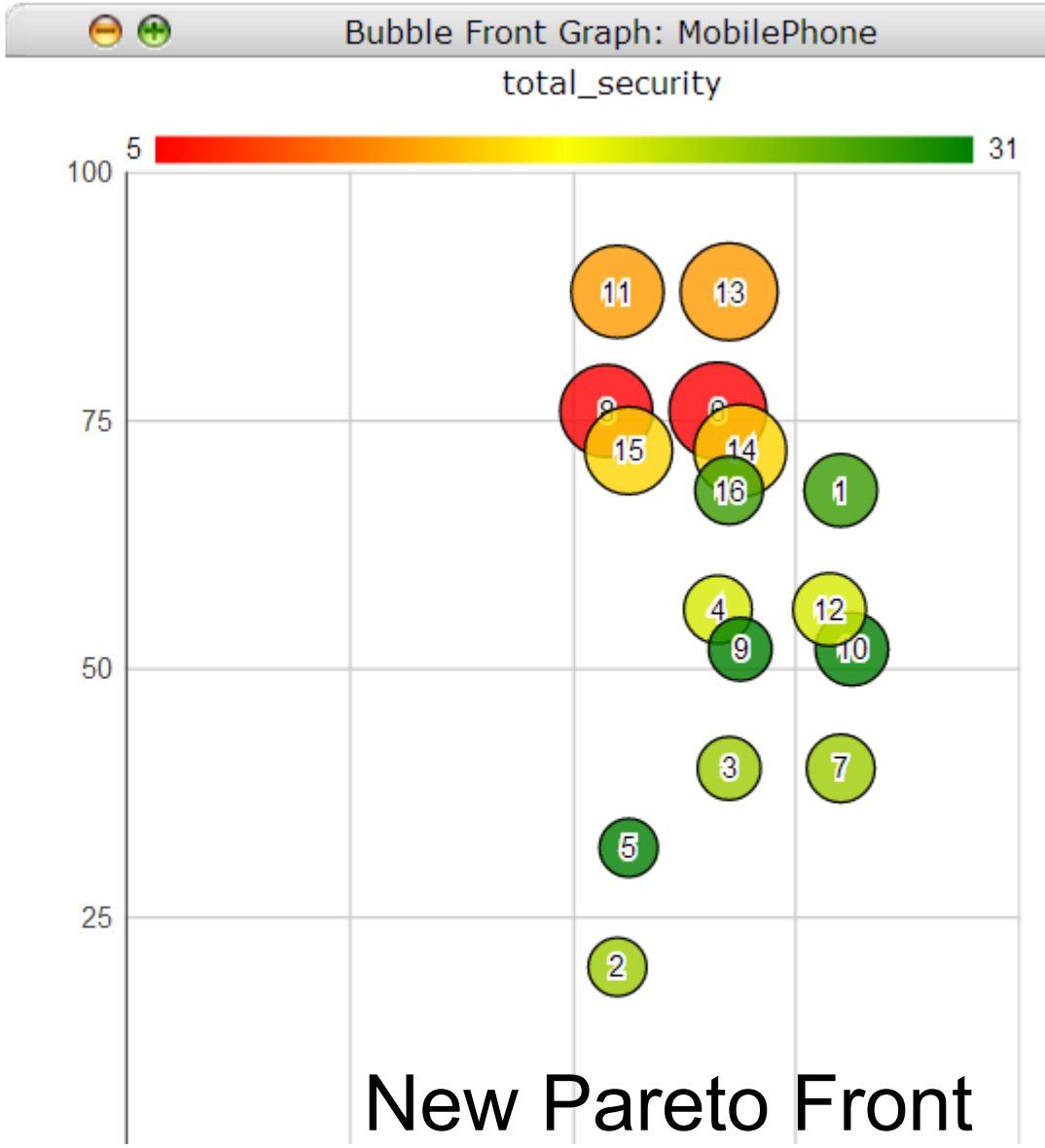


New Pareto Front

Product Line Evolution

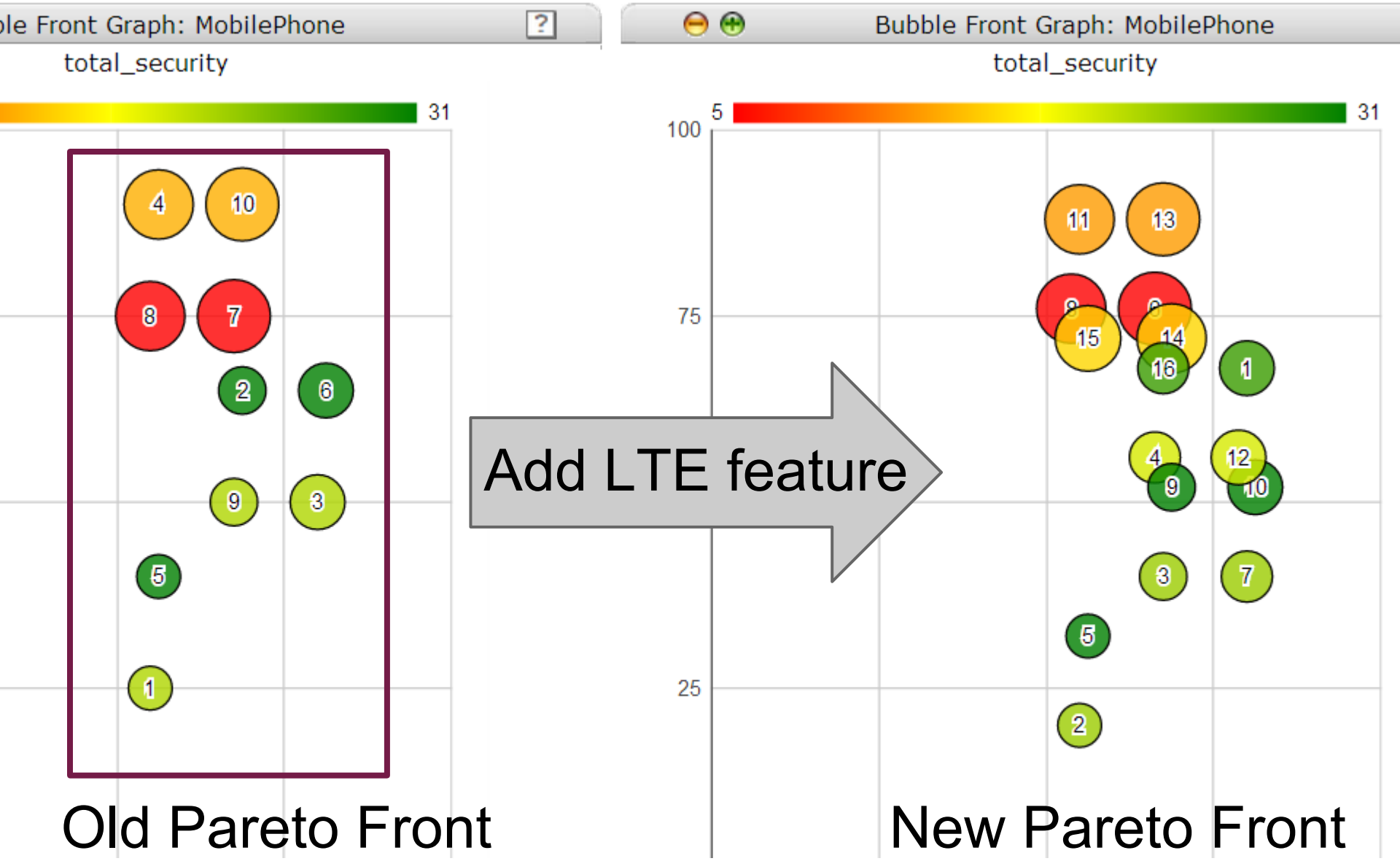


Old Pareto Front

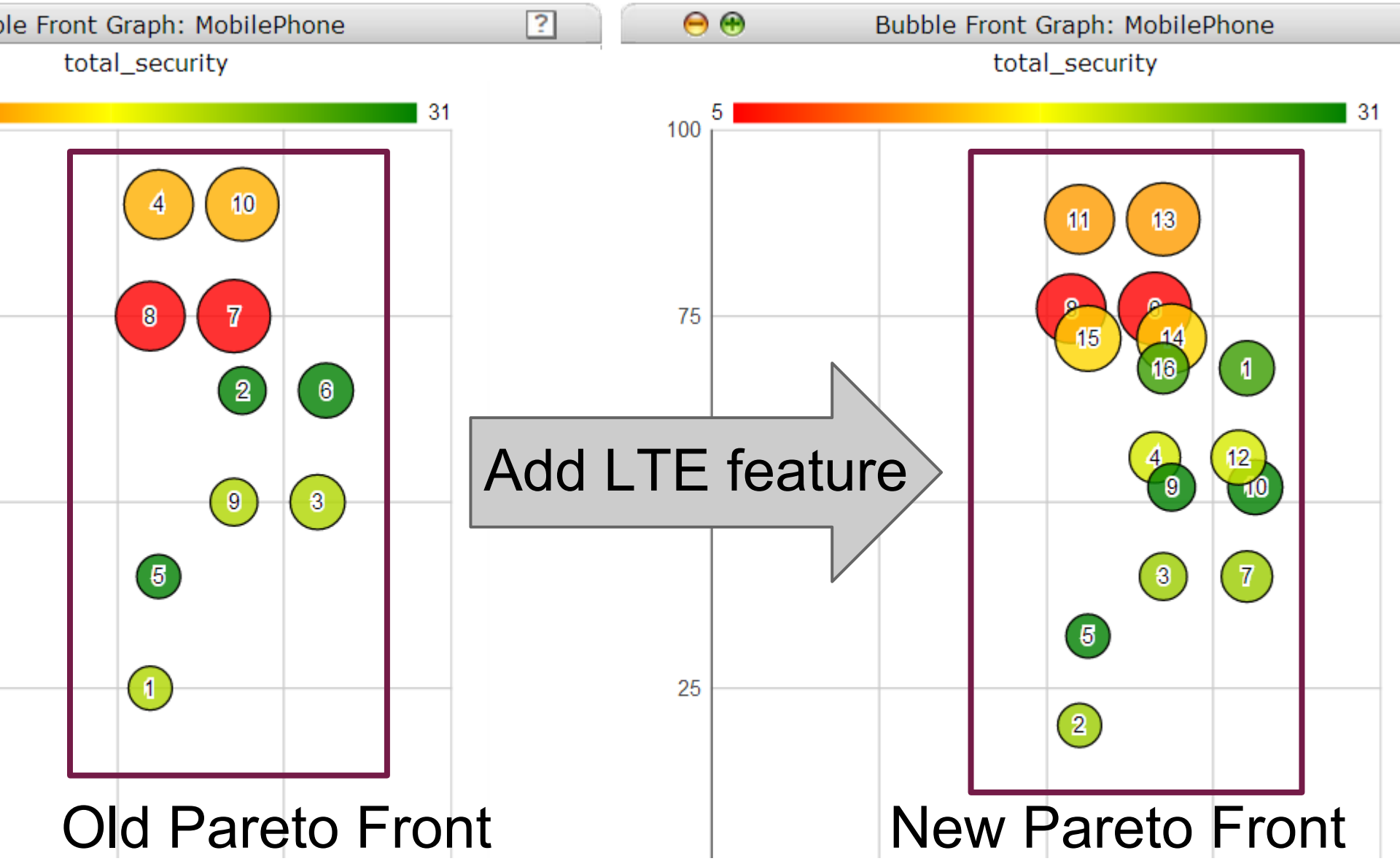


New Pareto Front

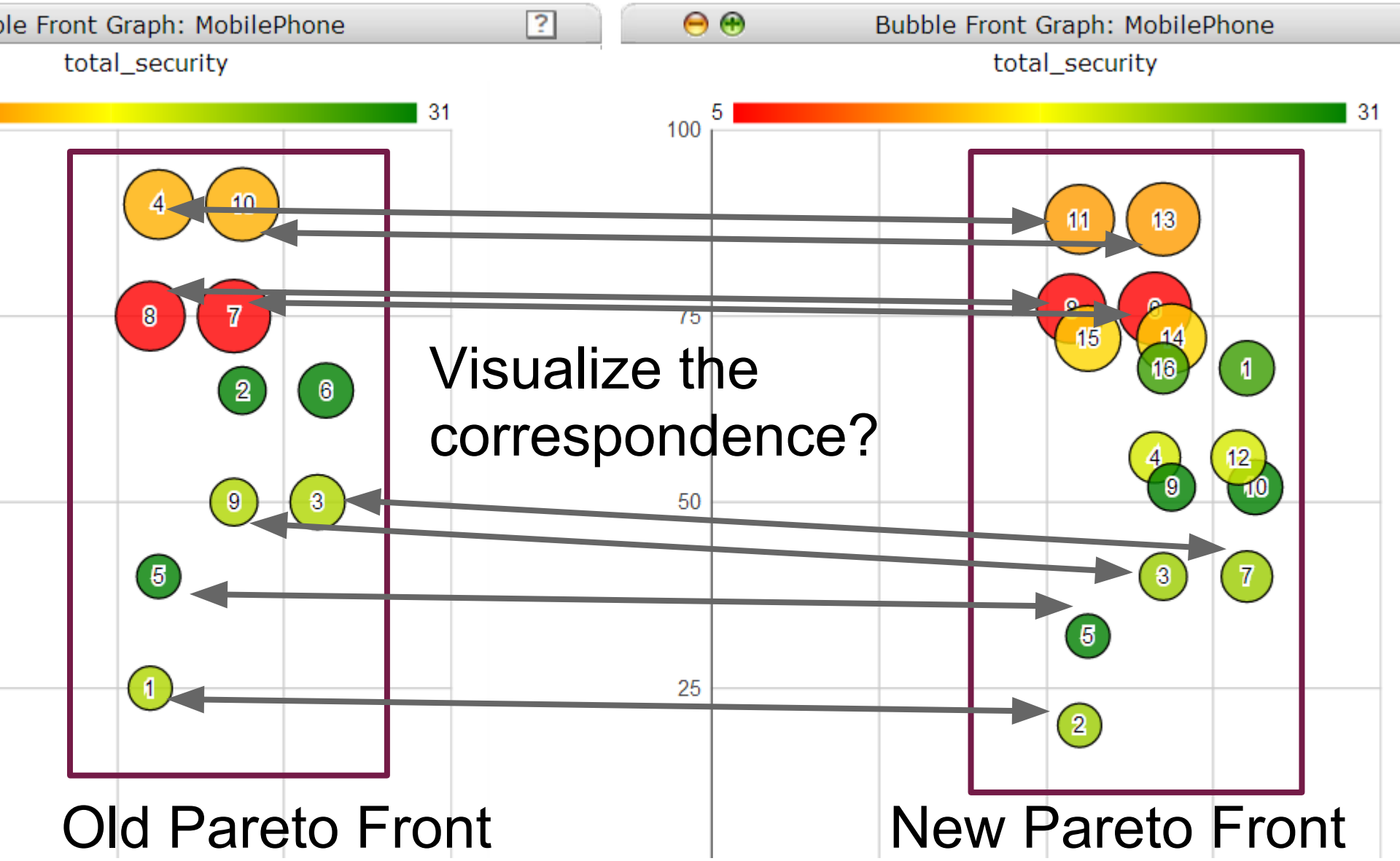
Product Line Evolution



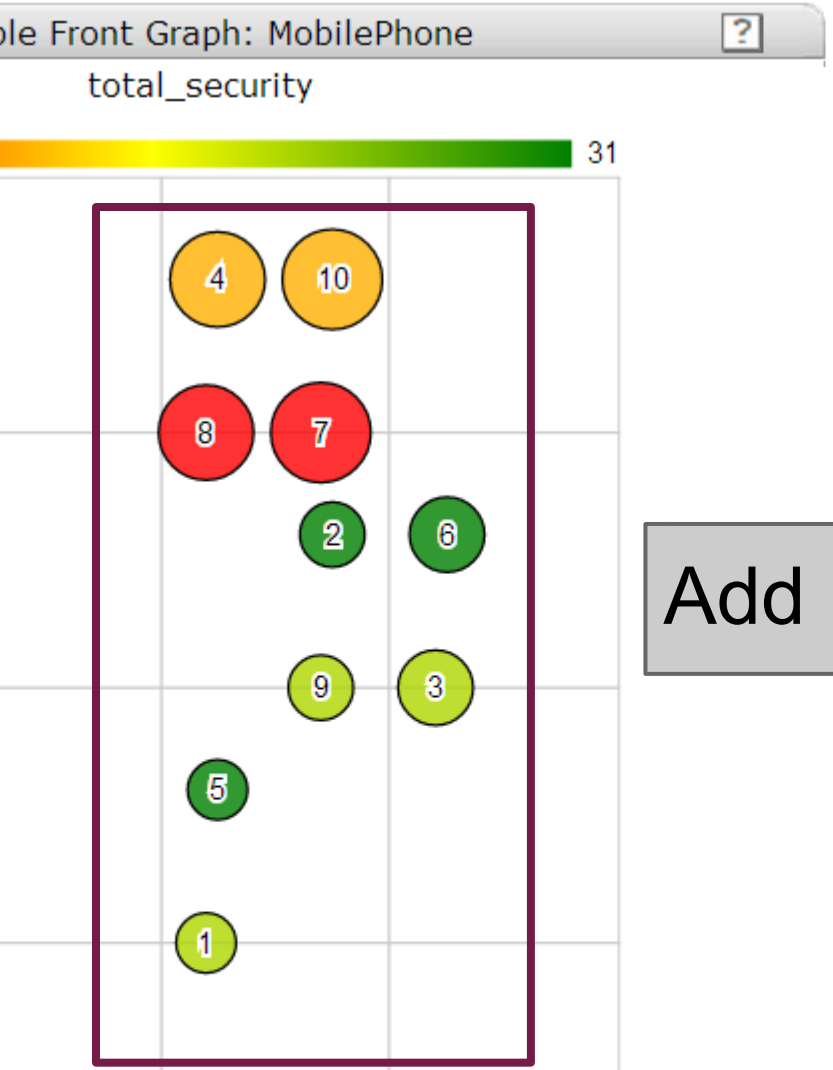
Product Line Evolution



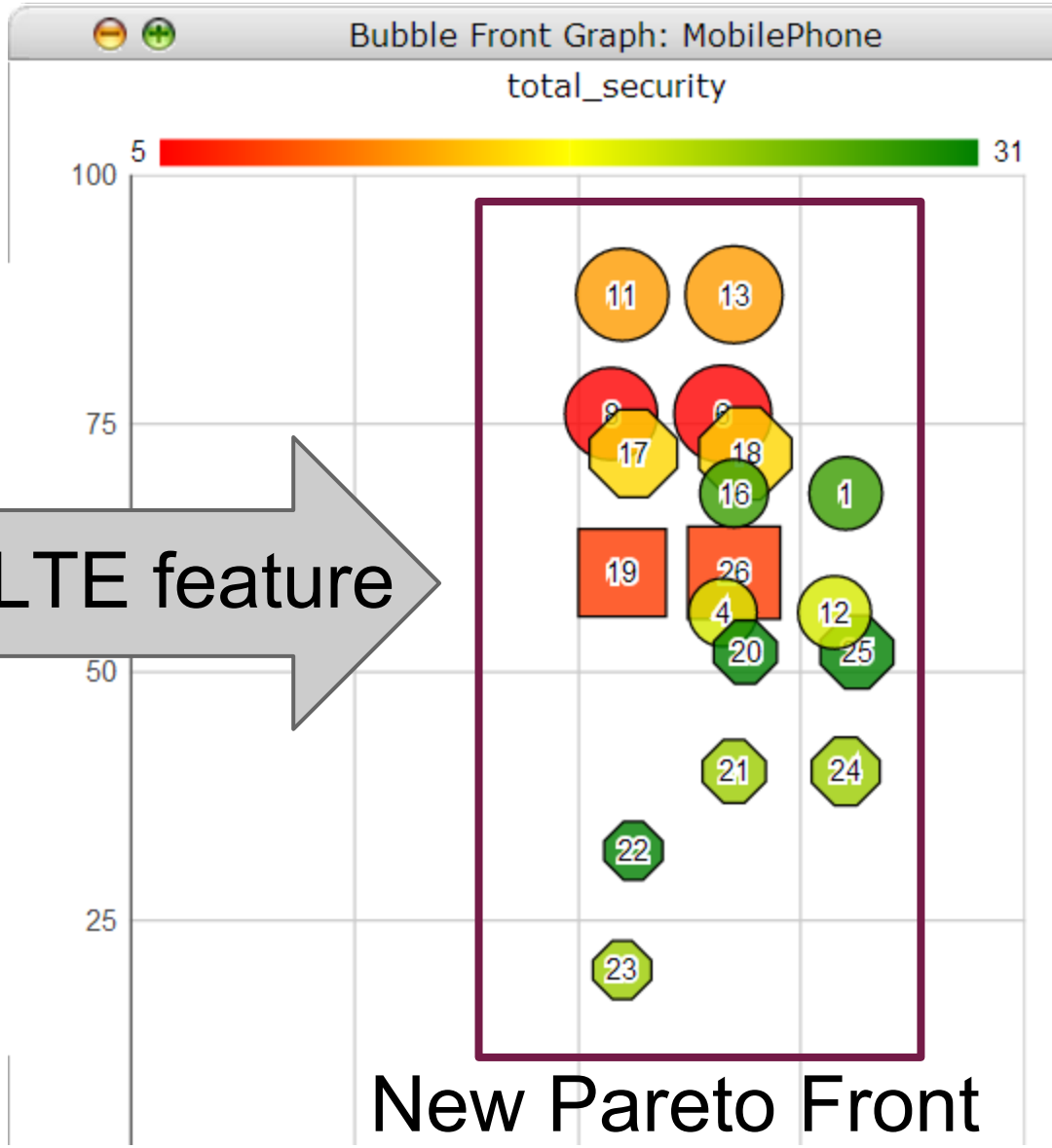
Product Line Evolution



Evolution: Our Approach



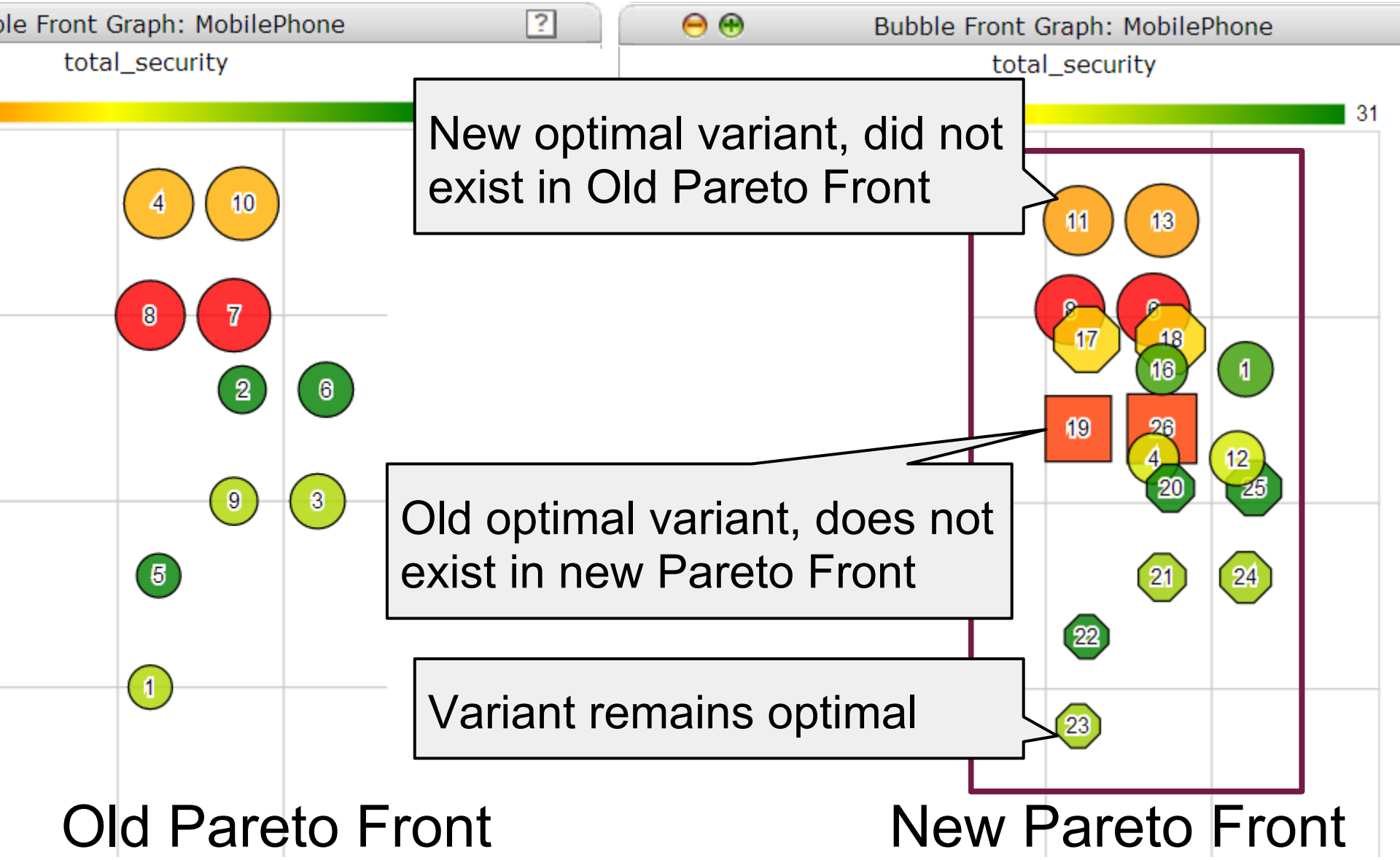
Add LTE feature



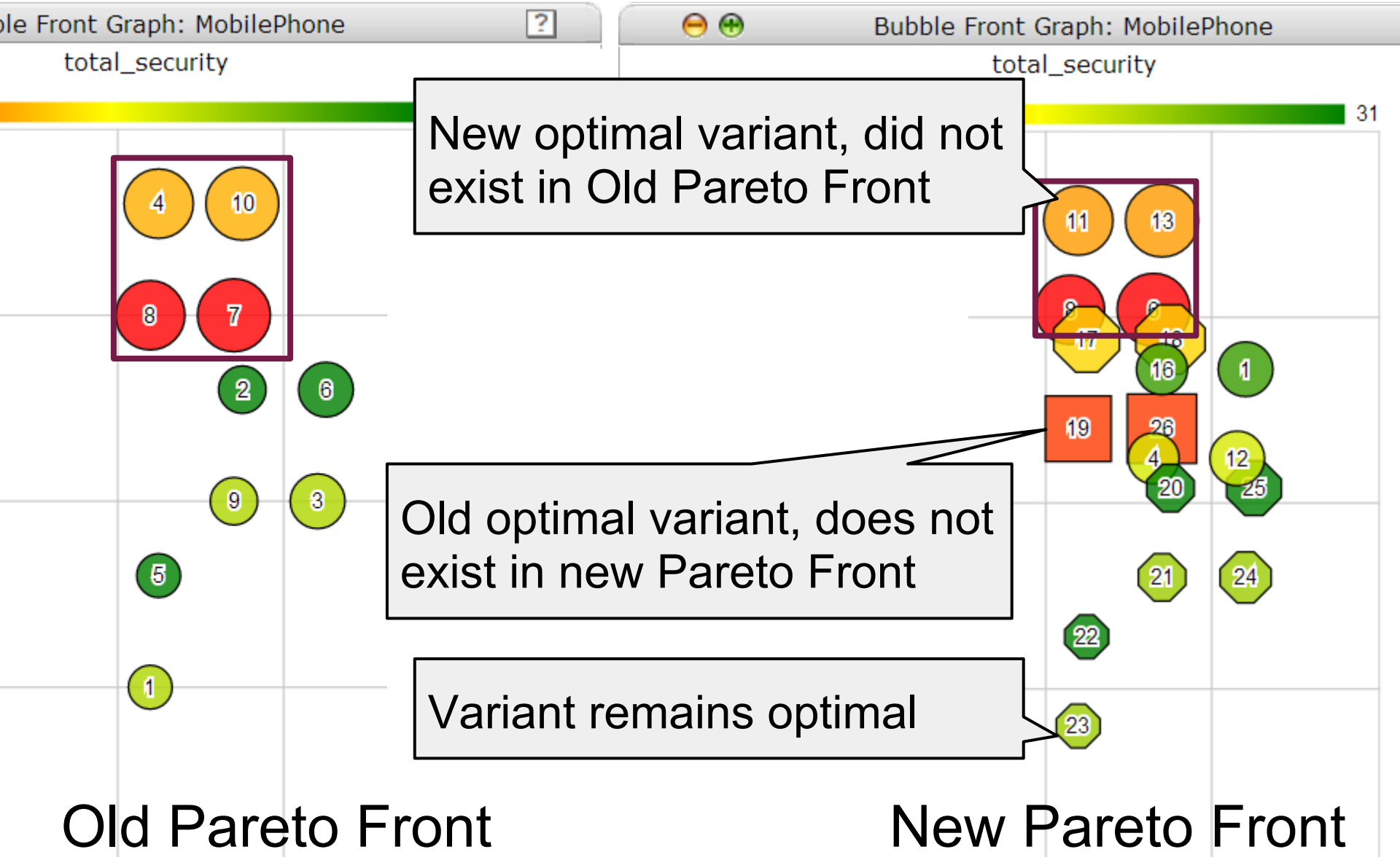
Old Pareto Front

New Pareto Front

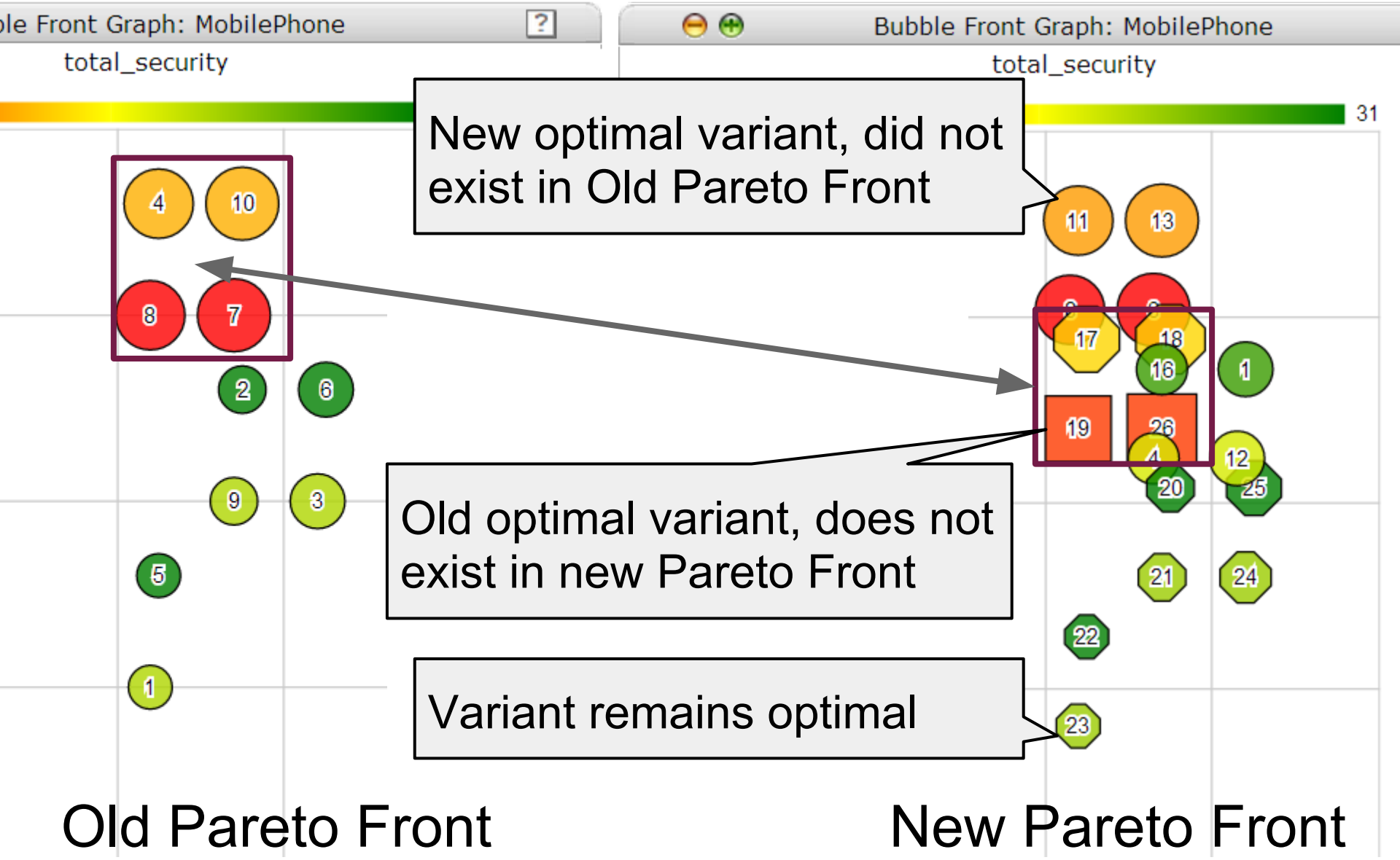
Evolution: Our Approach



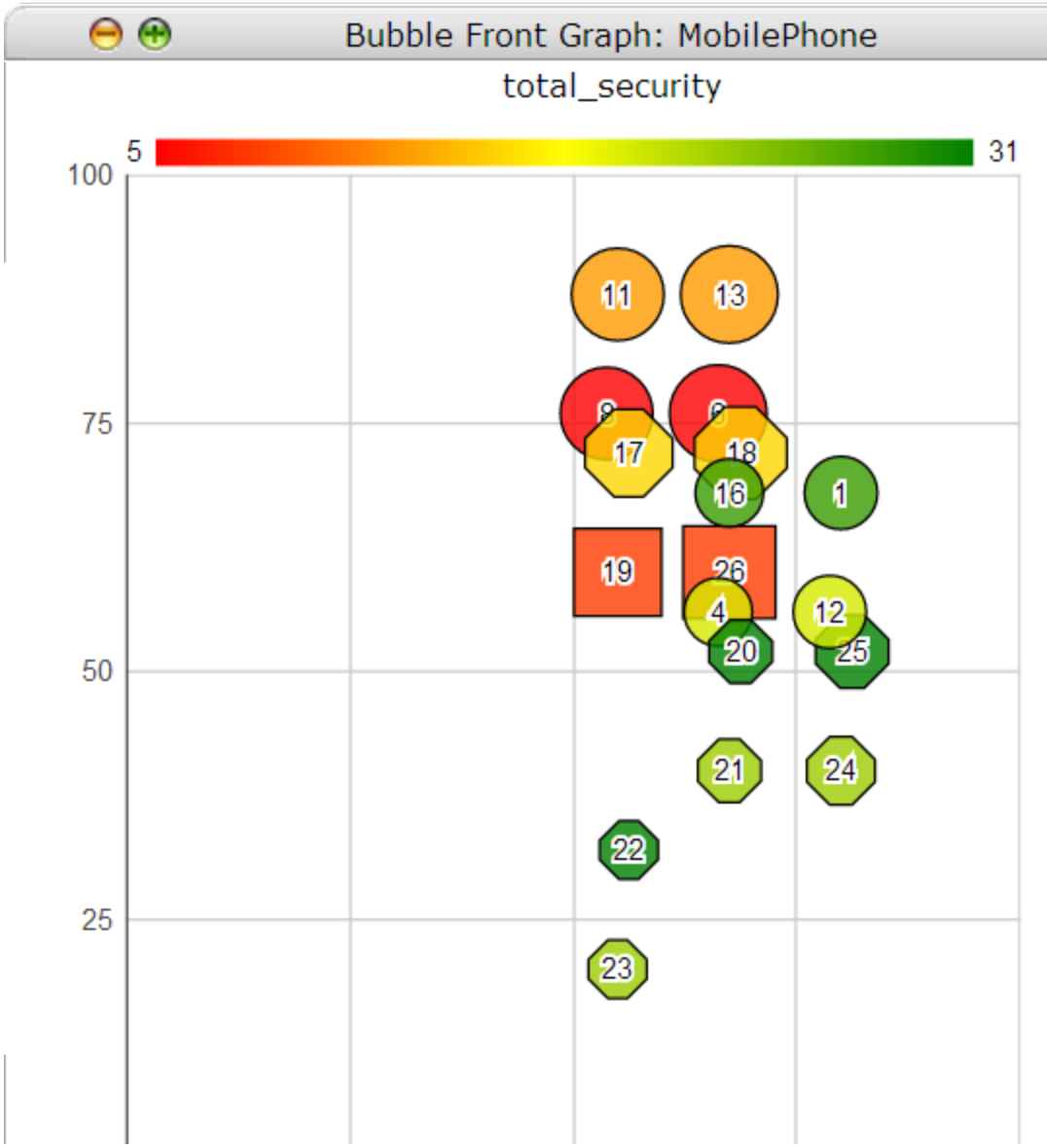
Evolution: Our Approach



Evolution: Our Approach



3.3 Observe Evolution of Variants



3.3 Observe Evolution of Variants

3.3 Observe Evolution of Variants

Variant Comparer

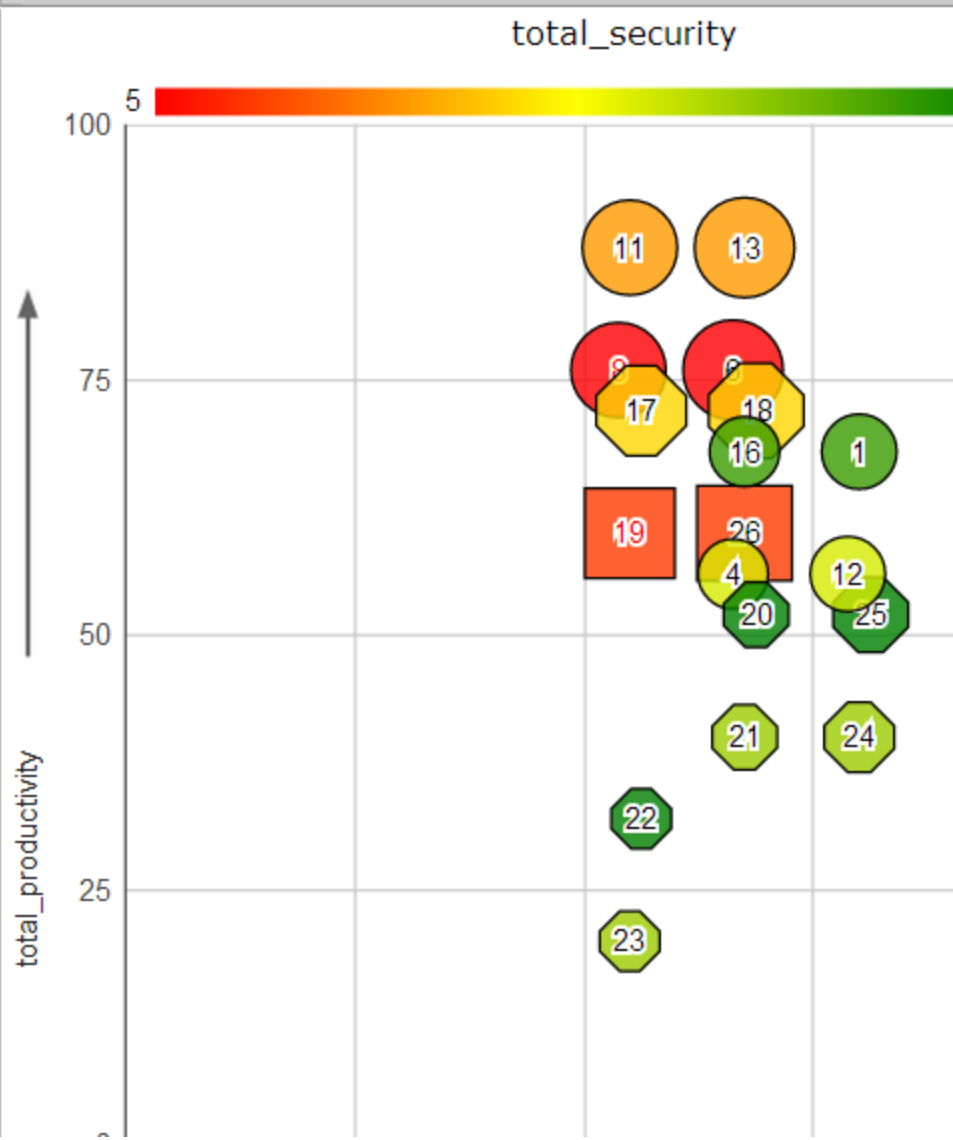
Clear [Complete] - The set defines a complete class

Save Selected

Commonalities	Value
Connectivity	✓
Bluetooth	✓
Bluetooth20EDR ?	⊘
Bluetooth21EDR ?	✓
Bluetooth40 ?	⊘
GSM	✓
WiFi ?	✓
USB ?	✓
Battery	✓
LiBattery1150 ?	✓
LiBattery1400 ?	⊘

Differences	× 8	× 19
LTE ?	✓	⊘
total_productivity	76	60
total_batterylife	43	44
total_security	5	8
total_cost	139	136

Bubble Front Graph: MobilePhone



3.3 Observe Evolution of Variants

Variant Comparer

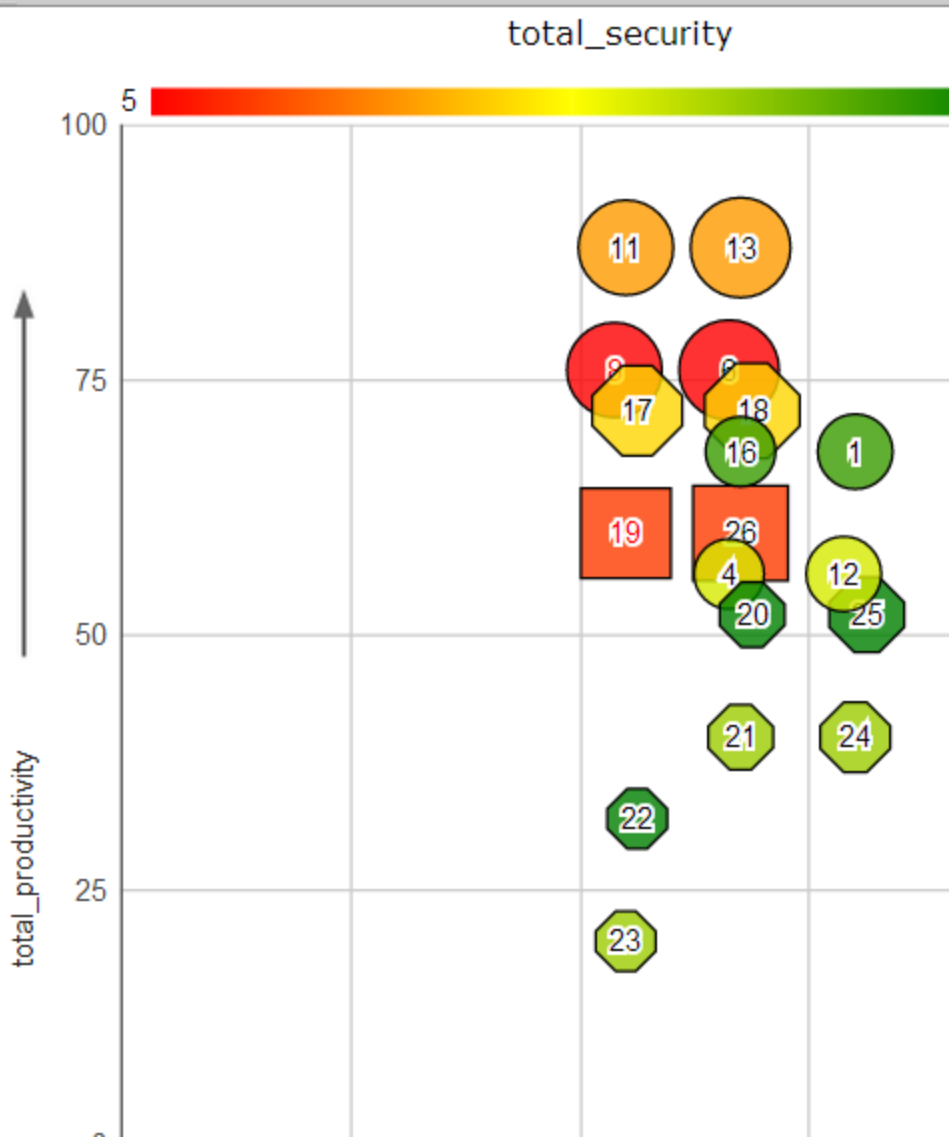
Clear [Complete] - The set defines a complete class

Save Selected

Commonalities	Value
Connectivity	✓
Bluetooth	✓
Bluetooth20EDR ?	⊘
Bluetooth21EDR ?	✓
Bluetooth40 ?	⊘
GSM	✓
WiFi ?	✓
USB ?	✓
Battery	✓
LiBattery1150 ?	✓
LiBattery1400 ?	⊘

Differences	× 8	× 19
LTE ?	✓	⊘
total_productivity	76	60
total_batterylife	43	44
total_security	5	8
total_cost	139	136

Bubble Front Graph: MobilePhone



3.3 Observe Evolution of Variants

Variant Comparer

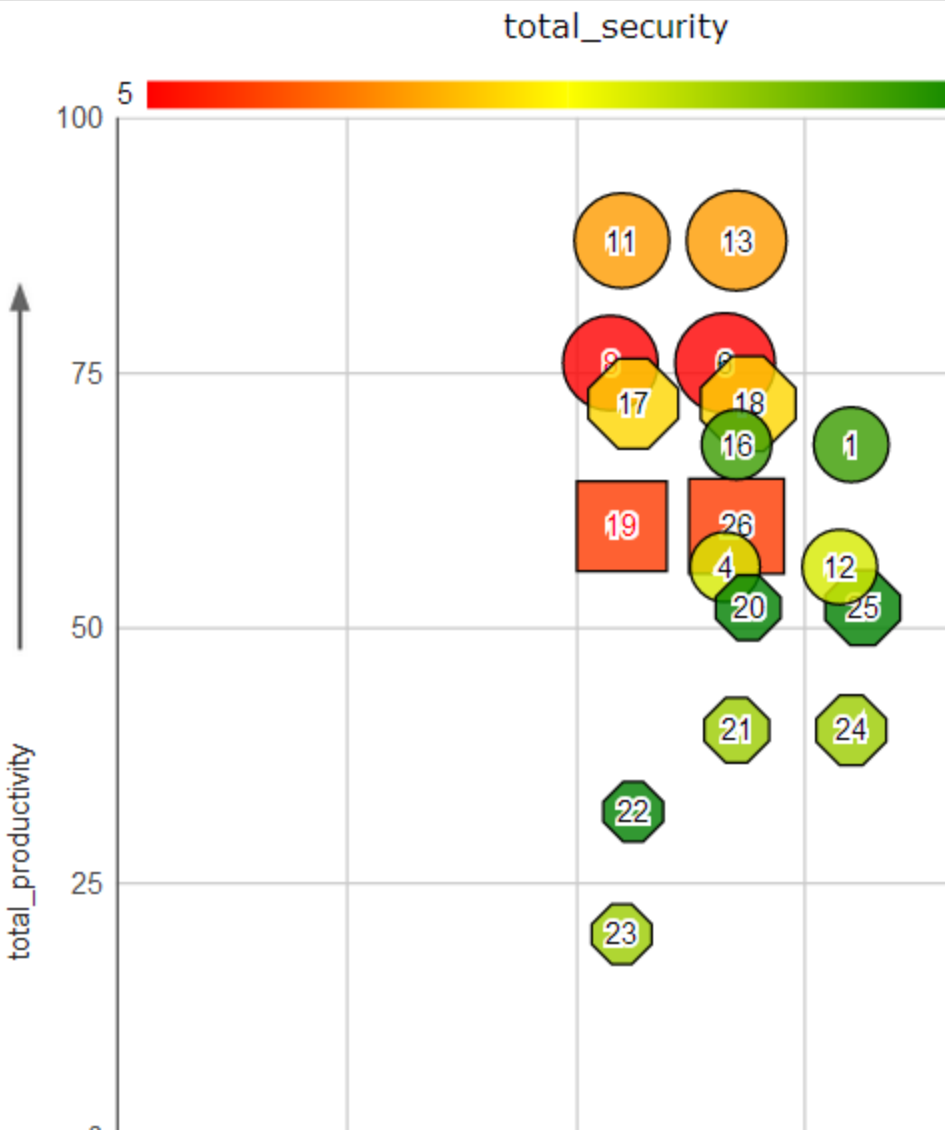
Clear [Complete] - The set defines a complete class

Save Selected

Commonalities	Value
Connectivity	✓
Bluetooth	✓
Bluetooth20EDR ?	⊘
Bluetooth21EDR ?	✓
Bluetooth40 ?	⊘
GSM	✓
WiFi ?	✓
USB ?	✓
Battery	✓
LiBattery1150 ?	✓
LiBattery1400 ?	⊘

Differences	× 8	× 19
LTE ?	✓	⊘
total_productivity	76	60
total_batterylife	43	44
total_security	5	8
total_cost	139	136

Bubble Front Graph: MobilePhone



Use Cases (3)

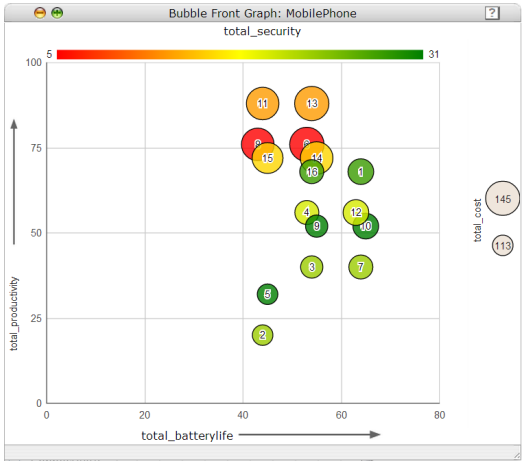
3.1 Explore variants **individually**?

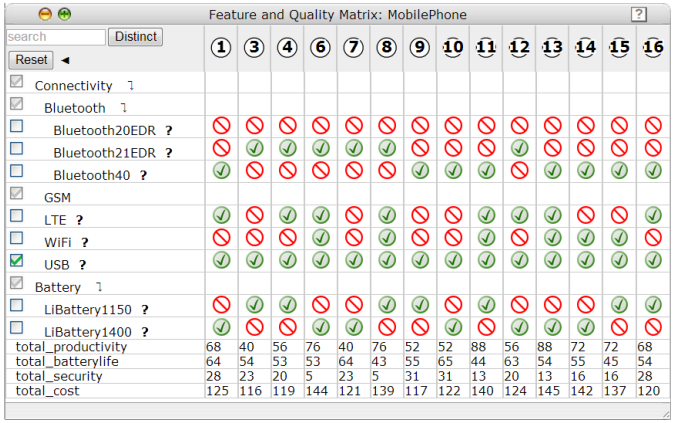
3.2 Select variants with a **similar** features?

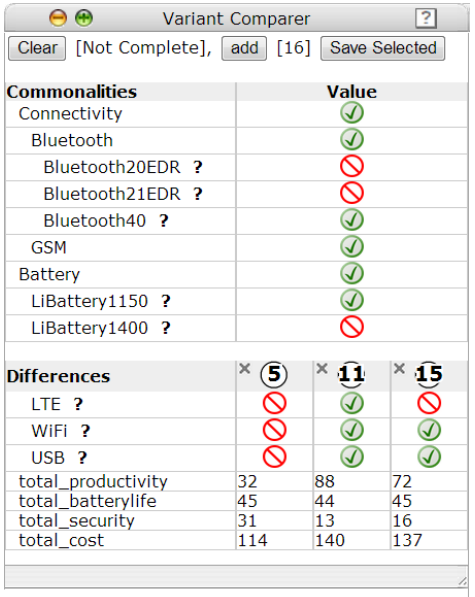
3.3 Observe **evolution** of optimal variants?

Visualization Methods Summary

- Interactive and synchronized views
- Open different perspectives
- Support 2 types of exploration:
  a. **top-down:** by features or quality
  b. **bottom-up:** by individual variants
- Support evolution of product lines







Related Work

- Not aware of any tool that implements interactive exploration of Pareto front in the PLE context

But:

- Visualizations used before and outside this domain
- Some formal notions:
  - Concept analysis: shared, distinct, rarely used or never used features [Loesch and Ploedereder, 2007]

Feature and Quality Matrix

Extension to a commonly-used matrix:

- variant matrix [D. Beuche, 2008]
- feature matrix [D. Nestor et. al., 2007]
- product-feature matrix [F. Loesch et. al., 2007]
- product map [J. Bayer et. al., 1999]
- ...

Feature and Quality Matrix:

- + Shows quality values also
- + Interactive

Bubble Front Graph

- Extension to Google's Bubble Chart
- Bubble Charts in multi-objective optimization:
  - Quality values and their deviations [Poles et. al., 2007]
  - With unlabeled bubbles [Sasaki et. al., 2001]
- Other approaches:
  - 3D Scatter plots [Tušar et.al., 2011]
  - Level Diagrams [Blasco et. al., 2008]
  - Heatmaps [Pryke et. al., 2007]
  - Self-organized maps [S. Obayashi and D. Sasaki, 2003]

Conclusions and Future Work

Conclusions:

- Explored Pareto front visualization methods in PLE
- Implemented and evaluated the tool

Future Work:

- User evaluation with professional engineers
- Explore industry use cases
- Tailoring to concrete use cases

ClaferMooVisualizer Online

Available online: http://gsd.uwaterloo.ca:5002