Provision of MOPs via web-apps for the rapid assessment of solder joint reliability

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Outline

- Design for Reliability: Challenges and Motivation
- Physics-of-Failure of a non-standard stress test: PCoB
- Provision of MOPs via web-apps
- Summary

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Design for Reliability: Challenges and Motivation
Trends influencing reliability requirements

Courtesy of U. Abelein (Infineon Tech. AG)

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Connectivity

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Autonomous Driving

E-mobility

Urbanization

Source: U. Abelein, “Challenges of Semiconductor Product Qualification for Extended Automotive Requirements”, IPC Automotive Electronics Reliability Forum, 2018

Design for Reliability: Challenges and Motivation
Contributing factors

Courtesy of U. Abelein (Infineon Tech. AG)

Table 45: Description General part

Operating situation	Operating situations: Vehicle parked	Charging cable inserted	High-voltage battery pack charging	Power line communication active (if available)
Driving operation	no	no	yes/no	no
Charging operation	yes	yes	yes	yes
Preconditioning	yes	yes/no	yes/no	yes/no
On-grid parking	yes	yes	no	yes
Off-grid parking or parking	yes	no	no	no

Contributing factors:

- Additional operating states beside driving:
  - On-grid parking
  - Vehicle-Preconditioning (battery as well as driver comfort like cabin heating)
  - Charging

Consequences:

- Longer operating times

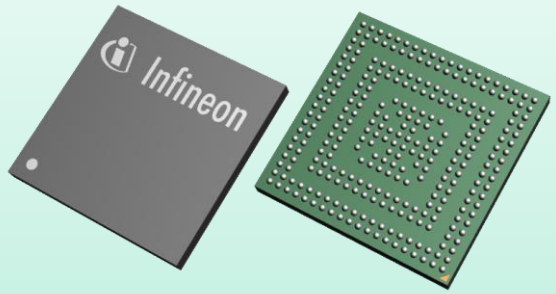
➔ **Increase in reliability requirements**

Source: U. Abelein, “Challenges of Semiconductor Product Qualification for Extended Automotive Requirements”, IPC Automotive Electronics Reliability Forum, 2018

Design for Reliability: Challenges and Motivation
Extended mission profiles (data from 2018)

Courtesy of Ulrich Abelein
(Infineon Technologies AG)

iRel 4.0
intelligent Reliability 4.0



Example:

Microcontroller for **use in a battery charging system**

Lifetime (same like vehicle): 15 years

- Op. Ambient Temp. Range: -40 °C to 125 °C
- Non-operating time: 91,400 hours
- Operating time: 40,000 hour

Customer's Mission Profile*

$T_{ambient}$ [°C]	Time [h]
Operating	
125	400
120	3,200
76	26,000
23	8,000
-40	2,400
Non Operating	
85	914
80	7,312
60	59,410
23	18,280
-40	5,484

*) Arbitrary chosen, corresponding to "Automotive Application Questionnaire for Electronic Control Units and Sensors", ZVEI, October 2006

How long would be the stress test duration according to AEC for this mission profile?

More details on Automotive Electronics Council (AEC): http://www.aecouncil.com/

Example: AEC-Q100 Rev H: http://www.aecouncil.com/Documents/AEC_Q100_Rev_H_Base_Document.pdf

Source: U. Abelein, "Challenges of Semiconductor Product Qualification for Extended Automotive Requirements", IPC Automotive Electronics Reliability Forum, 2018

Design for Reliability: Challenges and Motivation
Equivalent stress time (data from 2018) (1)

Courtesy of U. Abelein (Infineon Tech. AG)

iRel 4.0 intelligent Reliability 4.0

Equivalent HTSL stress test duration

Assumptions:

Arrhenius Model with E_a=0.7 eV, Self heating: 20 °C

Result:

$T_{stress,eq}$@175 °C = 1,521 h (>60 days!)

$T_{stress,eq}$@150 °C = 4,437 h (>180 days!)

Customer's Mission Profile*

$T_{ambient}$ [°C]	Time [h]
Operating	
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Long stress test durations no longer allow for experimental trial and error

→ Simulation-based Design for Reliability

More details on Automotive Electronics Council (AEC): http://www.aecouncil.com/

Example: AEC-Q100 Rev H: http://www.aecouncil.com/Documents/AEC_Q100_Rev_H_Base_Document.pdf

Source: U. Abelein, "Challenges of Semiconductor Product Qualification for Extended Automotive Requirements", IPC Automotive Electronics Reliability Forum, 2018

Design for Reliability: Challenges and Motivation
Equivalent stress time (data from 2018) (2)

Courtesy of U. Abelein (Infineon Tech. AG)

iRel 4.0 intelligent Reliability 4.0

Equivalent HTSL stress test duration

Assumptions:

Arrhenius Model with E_a=0.7 eV, Self heating: 20 °C

Result:

$T_{stress,eq}$@175 °C = 1,521 h (>60 days!)

$T_{stress,eq}$@150 °C = 4,437 h (>180 days!)

AEC-Q100 stress test conditions (Grade 1) ← **<30% coverage**

500 hours @ 175 °C or 1000 hours @ 150 °C

AEC-Q100 stress test conditions (Grade 0) ← **~60% coverage of extended requirement**

1000 hours @ 175 °C or 2000 hours @ 150 °C

➔ **Even today's AEC-Q100 Grade 0 would not cover those extended requirements!**

Customer's Mission Profile*

$T_{ambient}$ [°C]	Time [h]
Operating	
125	400
120	3,200
76	26,000
23	8,000
-40	2,400
Non Operating	
85	914
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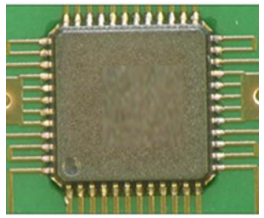
PoF of a non-standard stress test: PCoB
Exploring beyond standard stress tests

PCoB: Power Cycling on Board

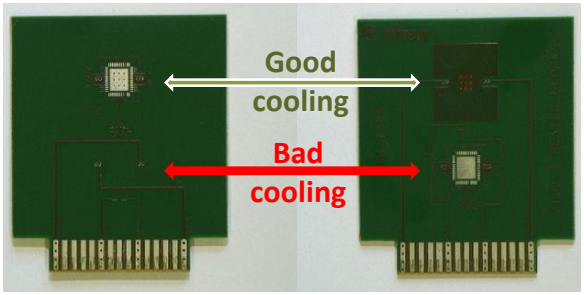
Test	AEC Q100 HTOL	AEC Q100 TC	AEC Q100 PTC	IPC9701 TCoB*	PCoB (this work)
Ambient temperature	—	↑↓	↑↓	↑↓	—
Active On/Off	Yes	No	Yes	No	Yes
Standard stress test	Yes	Yes	Yes	Yes	No
Focus	1st level	1st level	1st level	2nd level	2nd level

*TCoB: Temperature Cycling on Board
Sources: AEC Q100 Rev H, http://www.aecouncil.com , IPC9701 https://www.ipc.org/TOC/IPC-9701A.pdf , M. Zhang et al., EuroSimE 2022, doi: 10.1109/EuroSimE54907.2022.9758841



View of VQFN package soldered on PCB

A

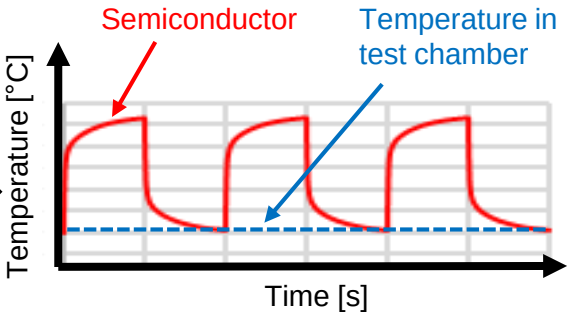


View of the test cards

B

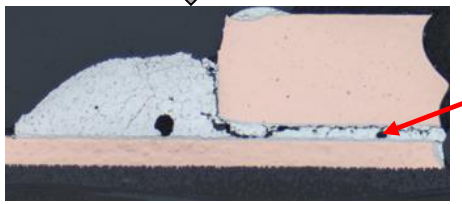
Test cards inside temperature chamber

C



View of temperature profile during test

D



Confirm failure modes

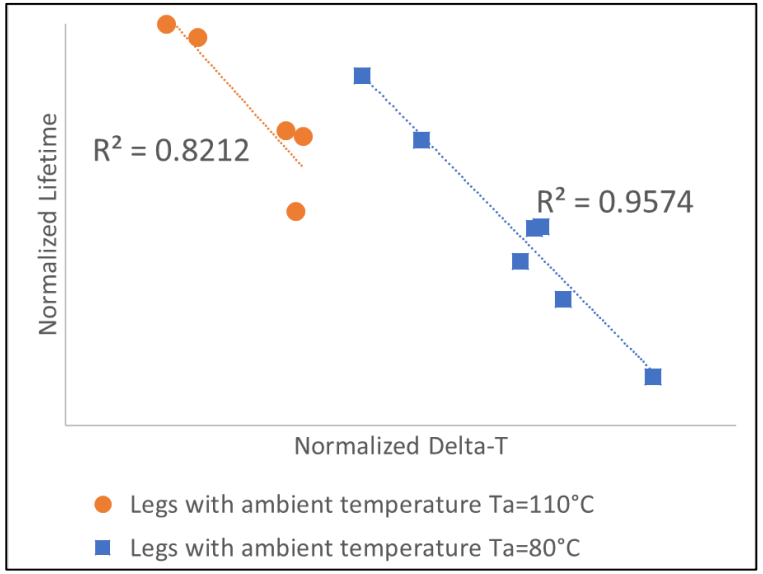
Solder fatigue crack

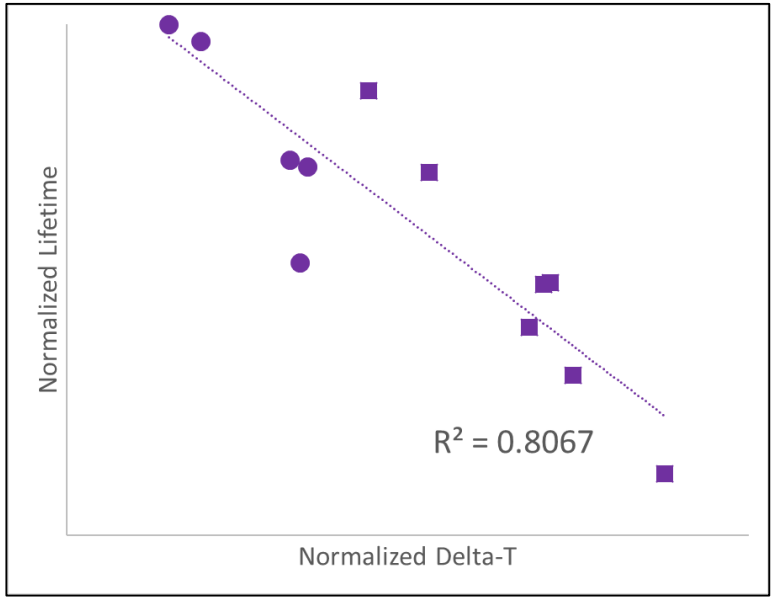
PoF of a non-standard stress test: PCoB
Correlation of experiment vs. analytical models

Series of test data was obtained at two ambient temperatures:

Name	Ambient temperature [°C]	Cooling of mount point	Heater Power level [norm.]	Delta-T (ΔT) [norm.]	On-/Off-Times [min]	Fatigue life [norm.]
Leg 01	110	good	140%	108%	5/5	86%
Leg 02		bad	140%	139%	5/5	28%
Leg 03		bad	100%	100%	5/5	100%
Leg 04		bad	132%	133%	5/5	29%
Leg 05		bad	139%	136%	15/15	12%
Leg 06	80	good	315%	246%	5/5	10%
Leg 07		bad	315%	322%	5/5	2%
Leg 08		good	234%	185%	5/5	26%
Leg 09		bad	234%	234%	5/5	7%
Leg 10		bad	158%	160%	5/5	60%
Leg 11		good	297%	242%	5/5	10%
Leg 12		good	315%	260%	15/15	4%

Attempts of fitting analytical acceleration models from, e.g. AEC Q100, on log-log-scale:

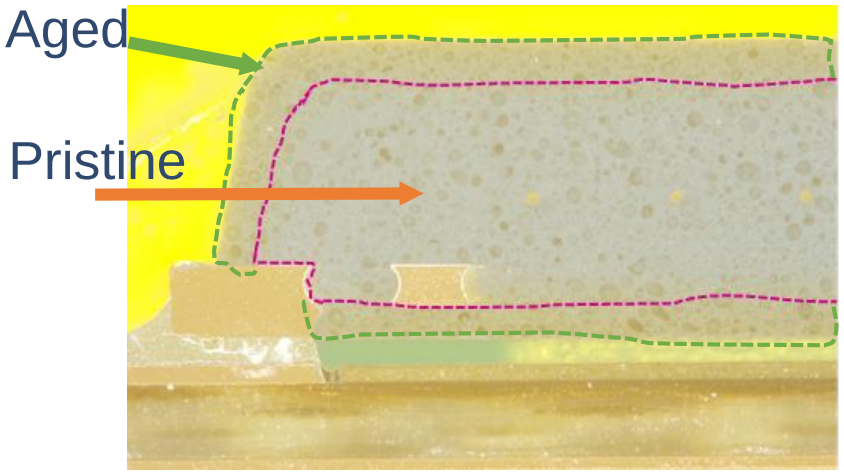




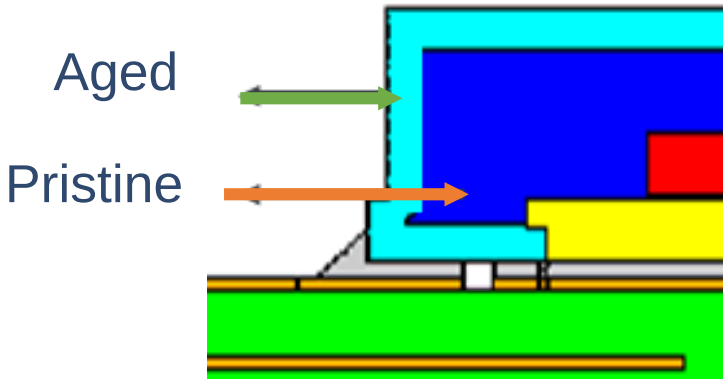
➔ **Analytical acceleration models do not allow for an accurate fit of all test data**

Sources: AEC Q100 Rev H, http://www.aecouncil.com
M. Zhang et al., EuroSimE 2022, doi: 10.1109/EuroSimE54907.2022.9758841

PoF of a non-standard stress test: PCoB
Correlation of experiment vs. simulation

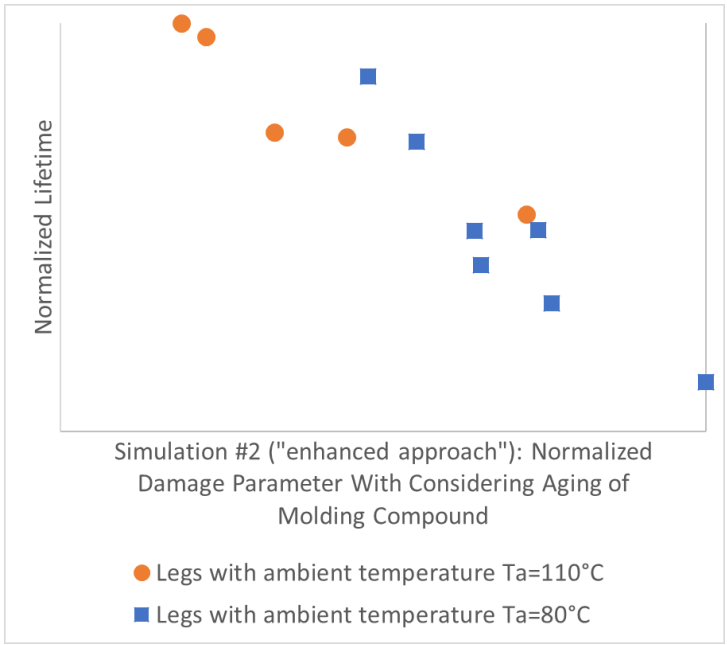


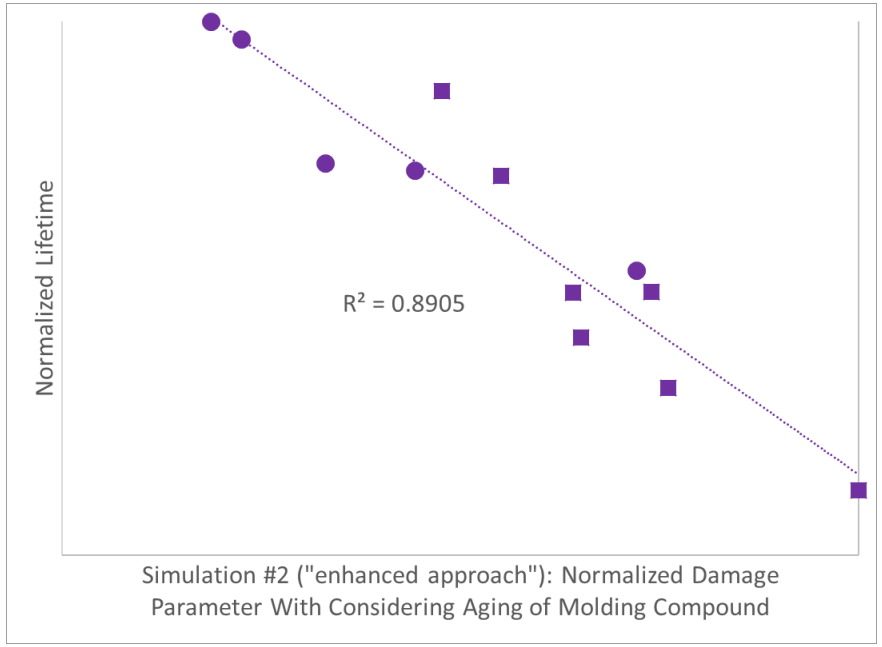
Cross section after PCoB test



Cross section of simulation model

Fitting of enhanced simulation considering aged layers of molding compound on log-log-scale





➔ **Enhanced simulation considering aged layers shows good correlation**

Sources: M. Zhang et al., EuroSimE 2022, doi: 10.1109/EuroSimE54907.2022.9758841

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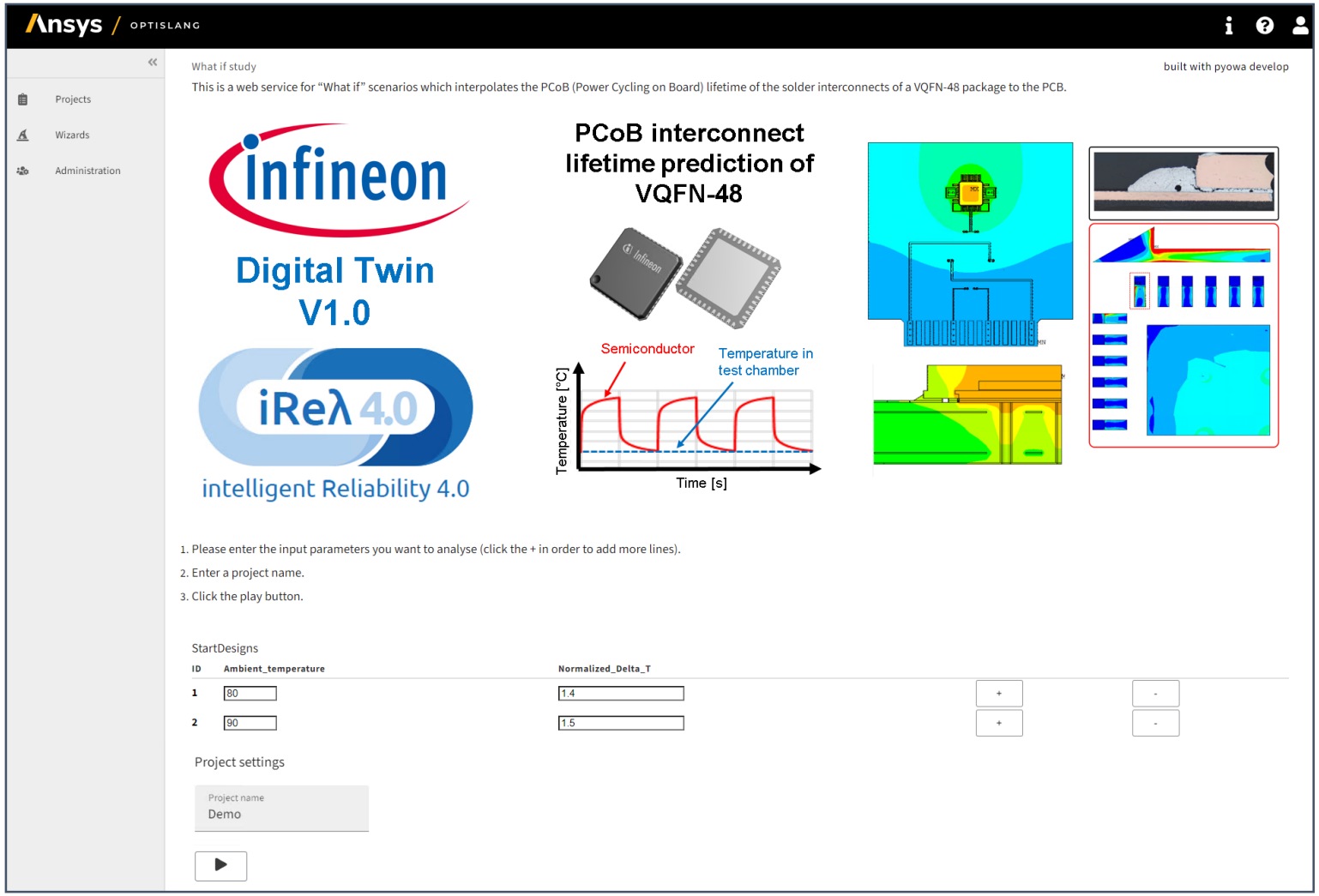
Provision of MOPs via web-apps
Motivation and interface (1)

- Sometimes, fast assessment of a component is needed for different ambient temperatures and power levels:

$T_{ambient}$ [°C]	Time [h]
Operating	
110	?
100	?
90	?
…	?

- Because computing one FEM simulation might take several hours:
  ➔ **Prepare MOPs and offer them via the optiSLang webservice**



Provision of MOPs via web-apps
Motivation and interface (2)

- Sometimes, fast assessment of a component is needed for different ambient temperatures and power levels:

$T_{ambient}$ [°C]	Time [h]
Operating	
110	?
100	?
90	?
…	?

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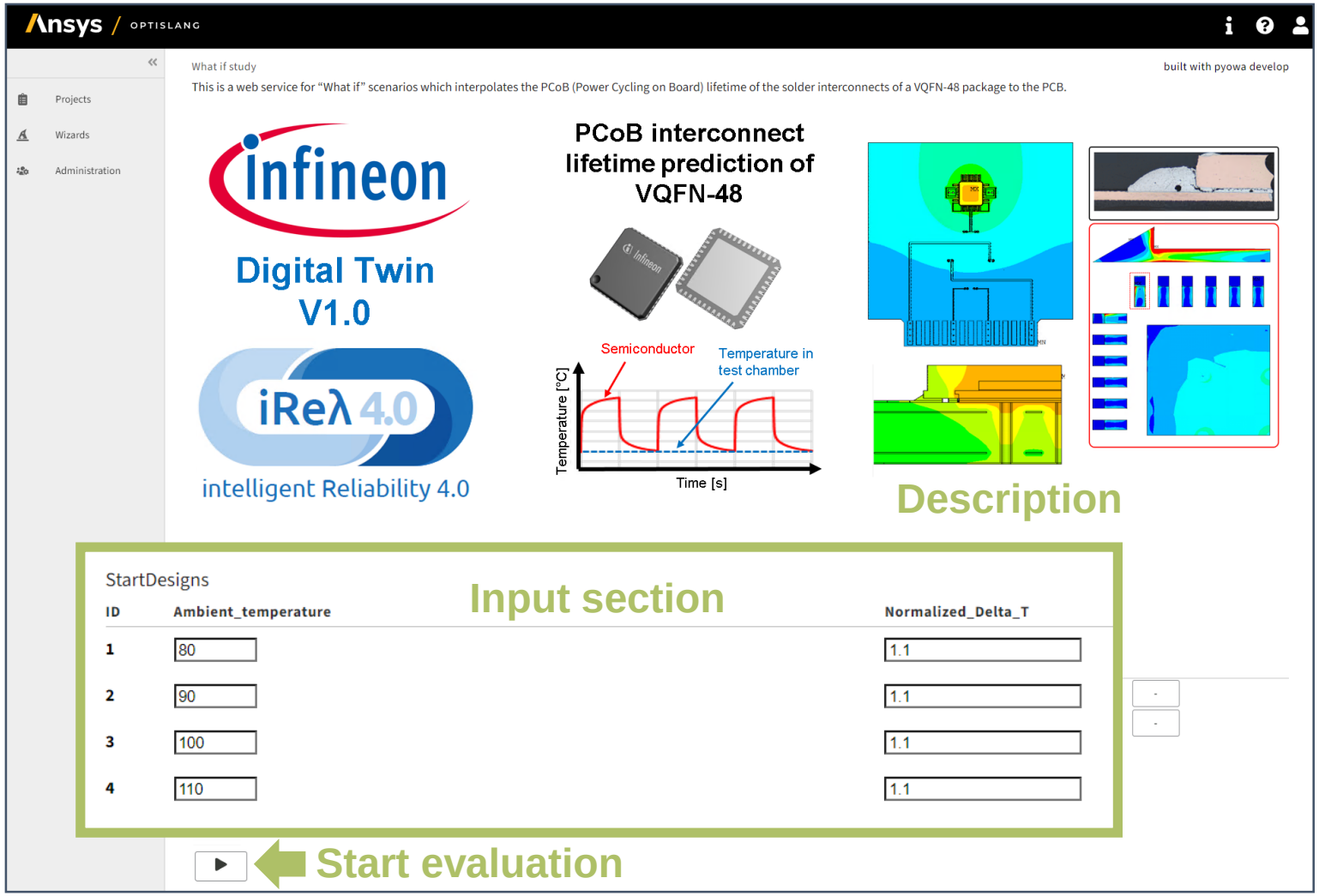
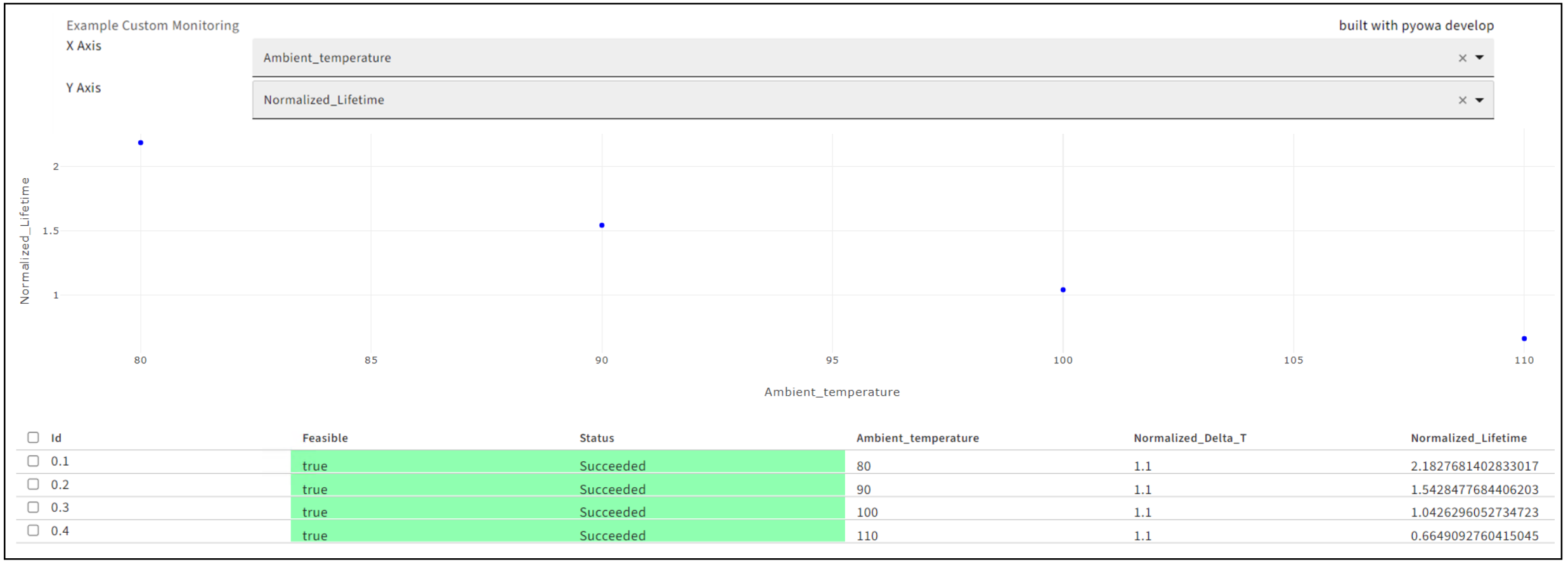


Provision of MOPs via web-apps
Result view with customized monitoring (1)

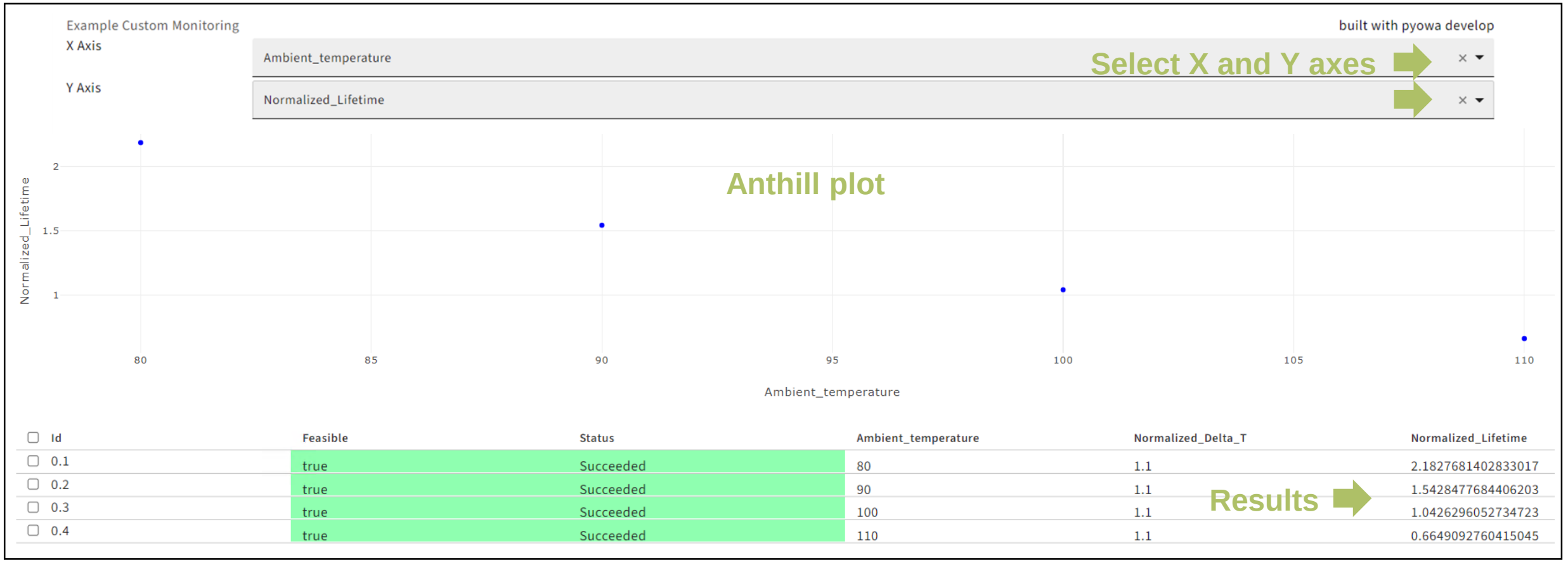


Id	Feasible	Status	Ambient_temperature	Normalized_Delta_T	Normalized_Lifetime
0.1	true	Succeeded	80	1.1	2.1827681402833017
0.2	true	Succeeded	90	1.1	1.5428477684406203
0.3	true	Succeeded	100	1.1	1.0426296052734723
0.4	true	Succeeded	110	1.1	0.6649092760415045

- Evaluation of results on MOP takes only a few seconds
- Rapid assessment by reliability engineers who are not simulation experts is enabled

Special thanks to Jonas Foerster!

Provision of MOPs via web-apps
Result view with customized monitoring (2)



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Results

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Summary

- Trend towards increased reliability requirements is expected
- Physics-of-Failure (PoF) of accelerated stress tests with long duration might not be captured completely with known analytical acceleration models
- More complex FEM simulations might be needed for capturing the full Physics-of-Failure (PoF) of accelerated stress tests with long duration
- MOPs provided via web-apps allow for rapid assessment and might be an alternative to analytical models

Thank you

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