MODELING QLC FLASH RELIABILITY

Nenad Miladinovic

INTRODUCTION

– Introduction of 3D NAND has put performance of TLC parts on par with performance of 2D MLC parts.

– The gap has emerged at the lower end of the endurance/reliability spectrum.

– QLC NAND flash is an emerging new technology that provides further reduction in $/GB at the lower end of performance range.

– What reliability targets are feasible with QLC?

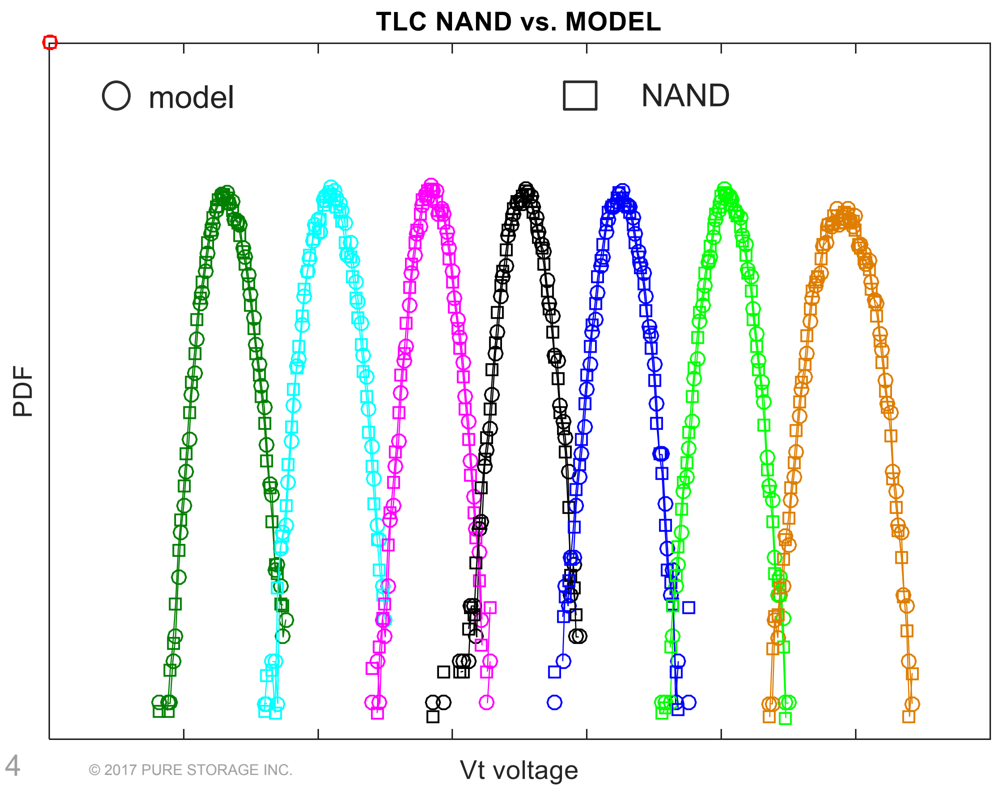
– Is QLC suitable for very large scale enterprise systems?

– NAND data collected from various generations of 2D and 3D SK Hynix NAND.

QLC NAND MODELING

- QLC NAND is built using same/similar device architecture as 3D TLC NAND.
- Range of Vt voltages is same as for 3D TLC NAND.
- Programming algorithm is same as for 3D TLC NAND (assuming more steps/time).
- To model NAND is to model the distribution of Vt voltages at particular endurance and retention condition.
- Building analytical model is hard => USE MACHINE LEARNING
- A machine learning (ML) model is trained with TLC data for a particular condition (PE/RETENTION).
- A ML model is used to predict behavior of a QLC NAND for the same condition and desired erase/program/read behavior.

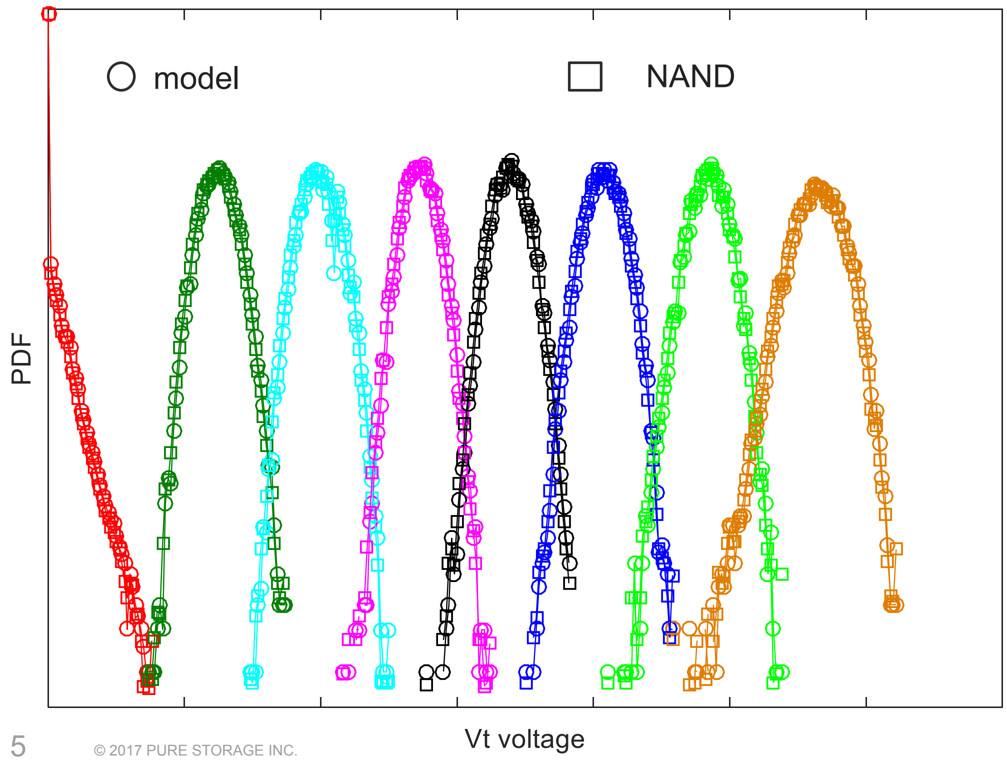
MODEL VALIDATION PE0/NO RETENTION



– Plot depicts the matching between Vt voltage distribution data collected on TLC NAND and Vt distribution generated by 3D TLC model for new NAND.

– Data validates that model fits the collected Vt voltage distribution with high fidelity.

MODEL VALIDATION PE800/6M0 RETENTION



– The ML model is validated across different endurance and retention conditions and achieves very high accuracy.

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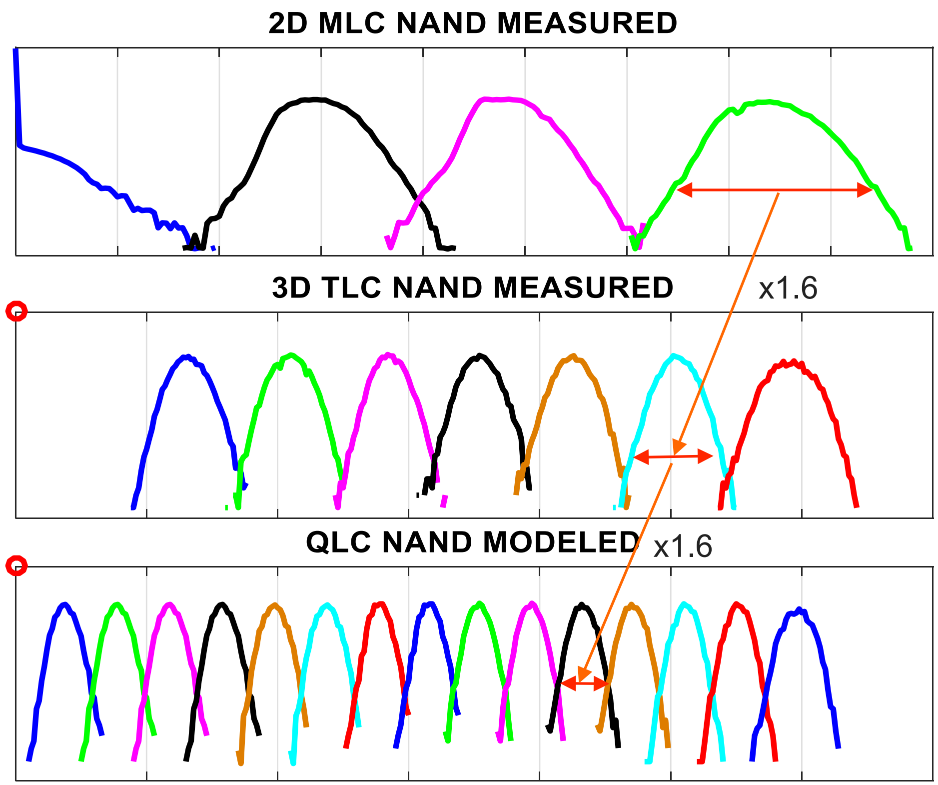
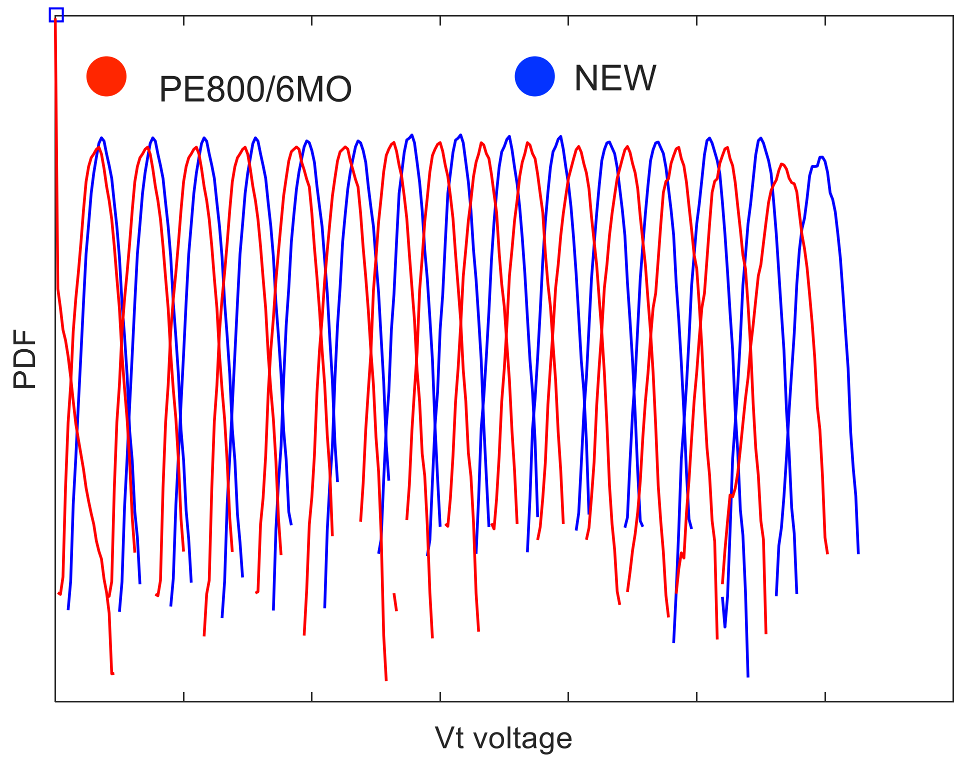
MODELING MLC-TLC-QLC



- The range of Vt voltage is same for 2D MLC, 3D TLC and future 3D QLC NAND.
- More precise Vt placement is needed in TLC compared to MLC, reduction in Vt variance by factor x1.6
- Assume same reduction in Vt variance can carry over to QLC.

QLC 6MO RETENTION EFFECT AT PE800



– Plot illustrates the effect of 6 month retention at 40C in modeled QLC NAND with 800 P/E cycles.

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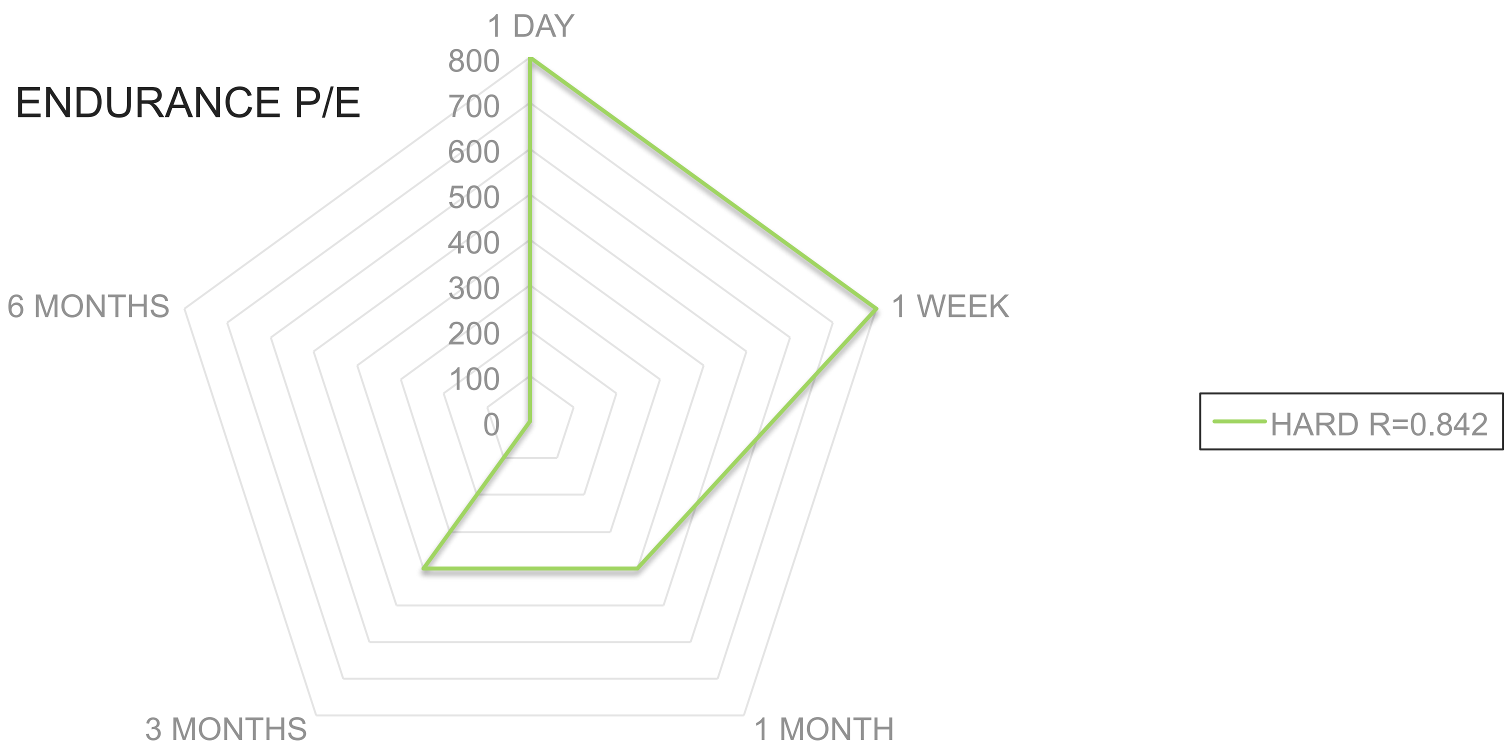
SIMULATION SETUP

- For each PE/Retention condition train ML model using data from 3D TLC parts.
- Use the ML model create corresponding QLC Vt distribution for a given condition.
- Software simulator emulates QLC NAND read by generating Vt voltages corresponding to QLC Vt distribution.
- Software simulator applies desired read mode, hard read, single bit soft read, 3bit soft read or full soft read (maximum resolution of Vt voltage).
- Simulate three different QLC models, corresponding to variance reduction factor 1.6, 1.75 and 2 compared to TLC parts.
- Simulate LDPC codes with code rate 0.889, 0.877, 0.865, 0.853, 0.842 and 0.831.
- Simulate read of 10 million LDPC code words for hard read and single bit soft read mode.

RELIBAILITY ESTIMATE FACTOR x1.6



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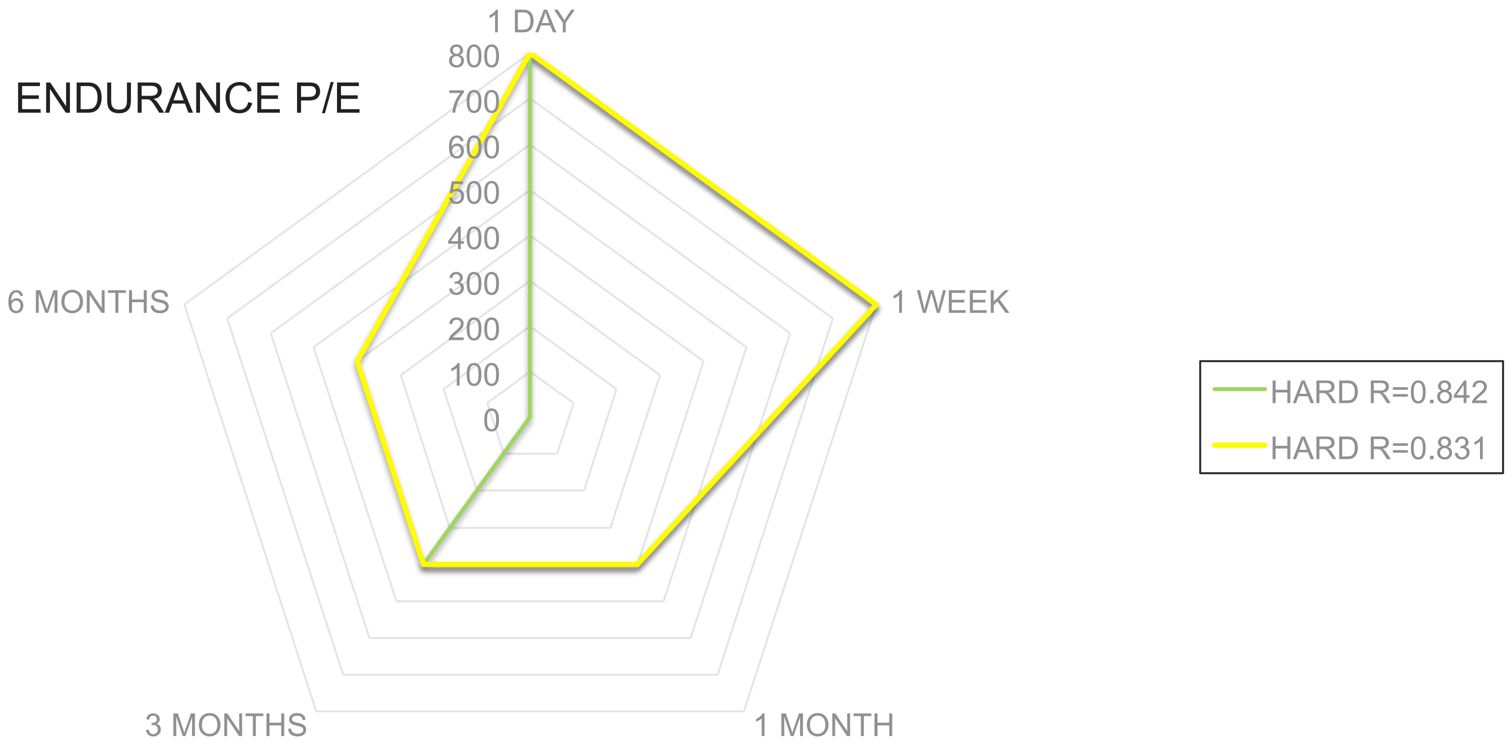
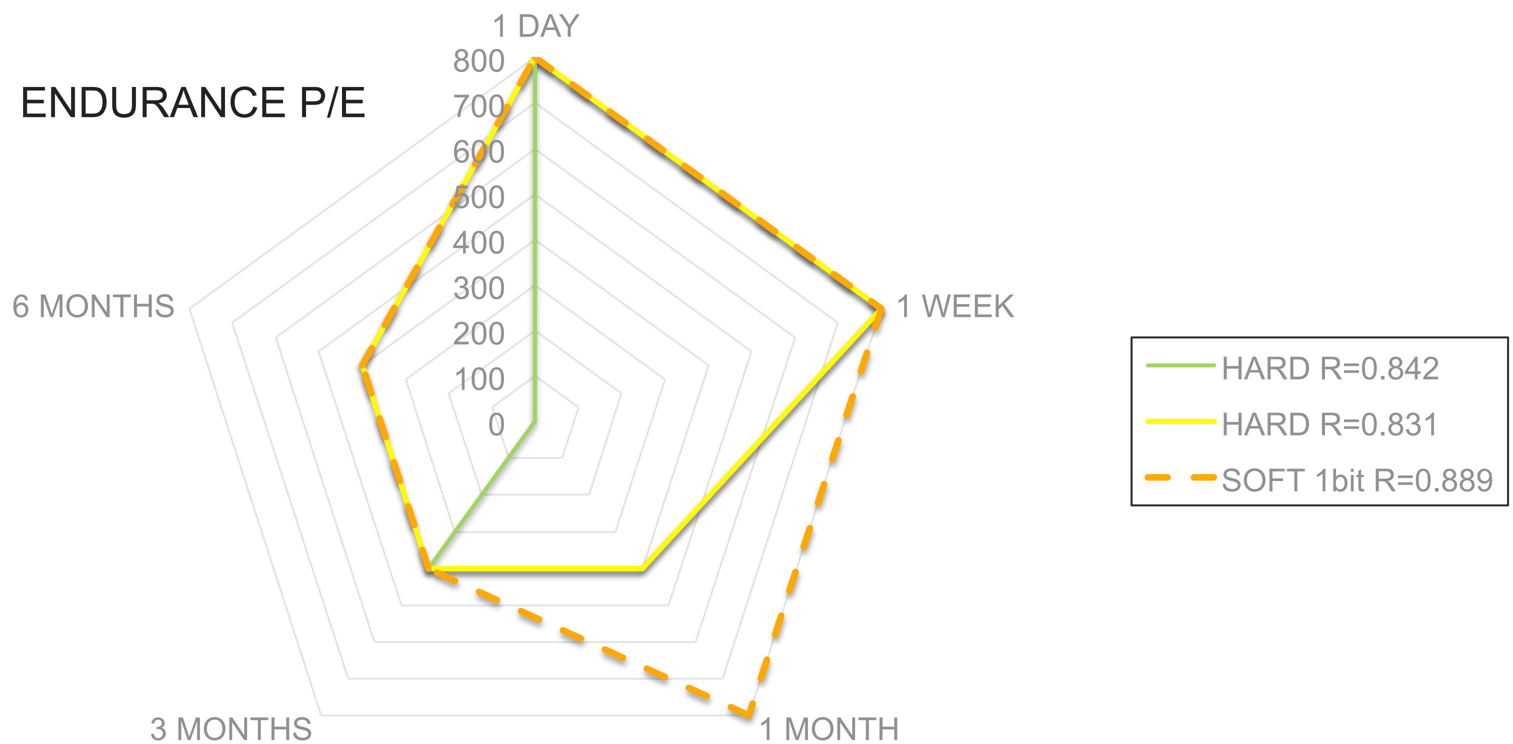
RELIBAILITY ESTIMATE FACTOR x1.6



RELIBAILITY ESTIMATE FACTOR x1.6



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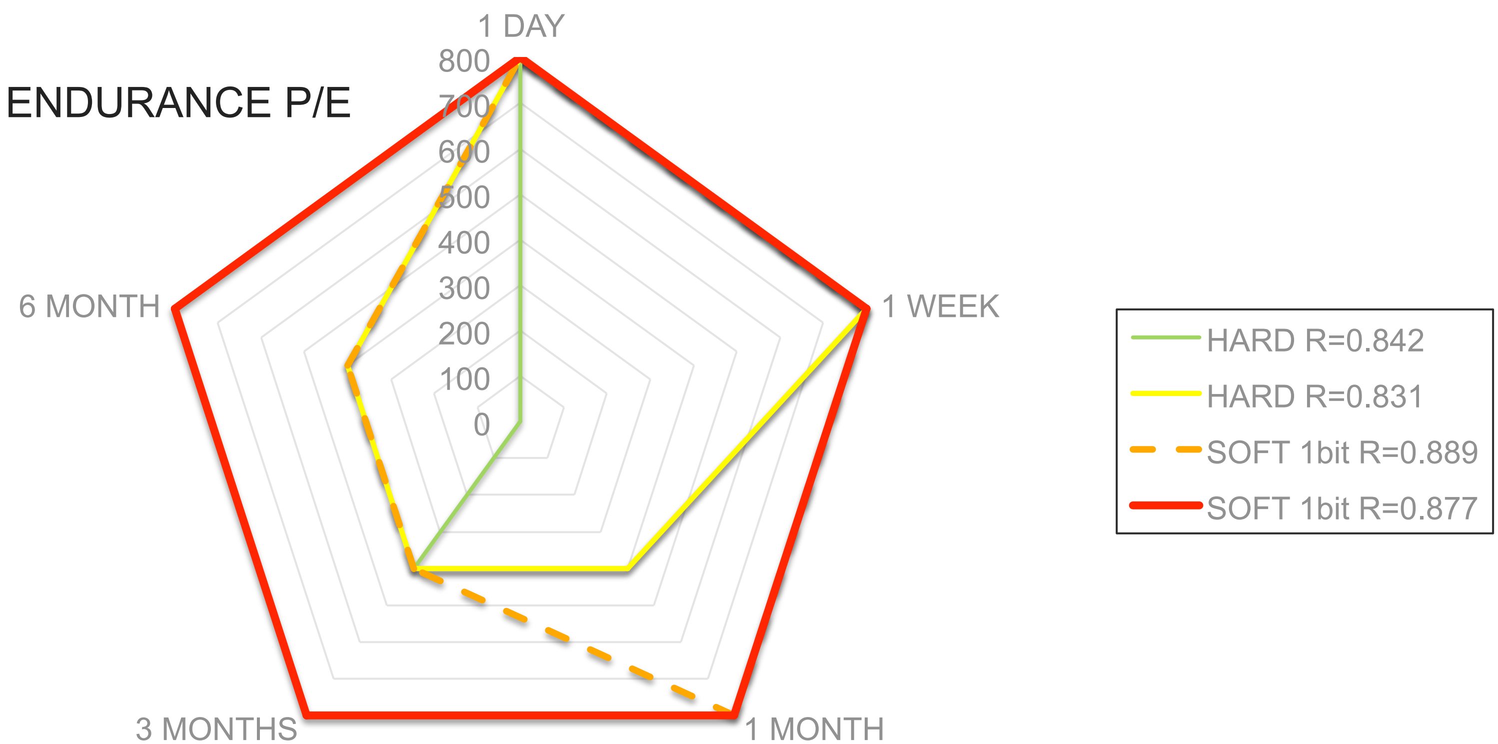
RELIBAILITY ESTIMATE FACTOR x1.6



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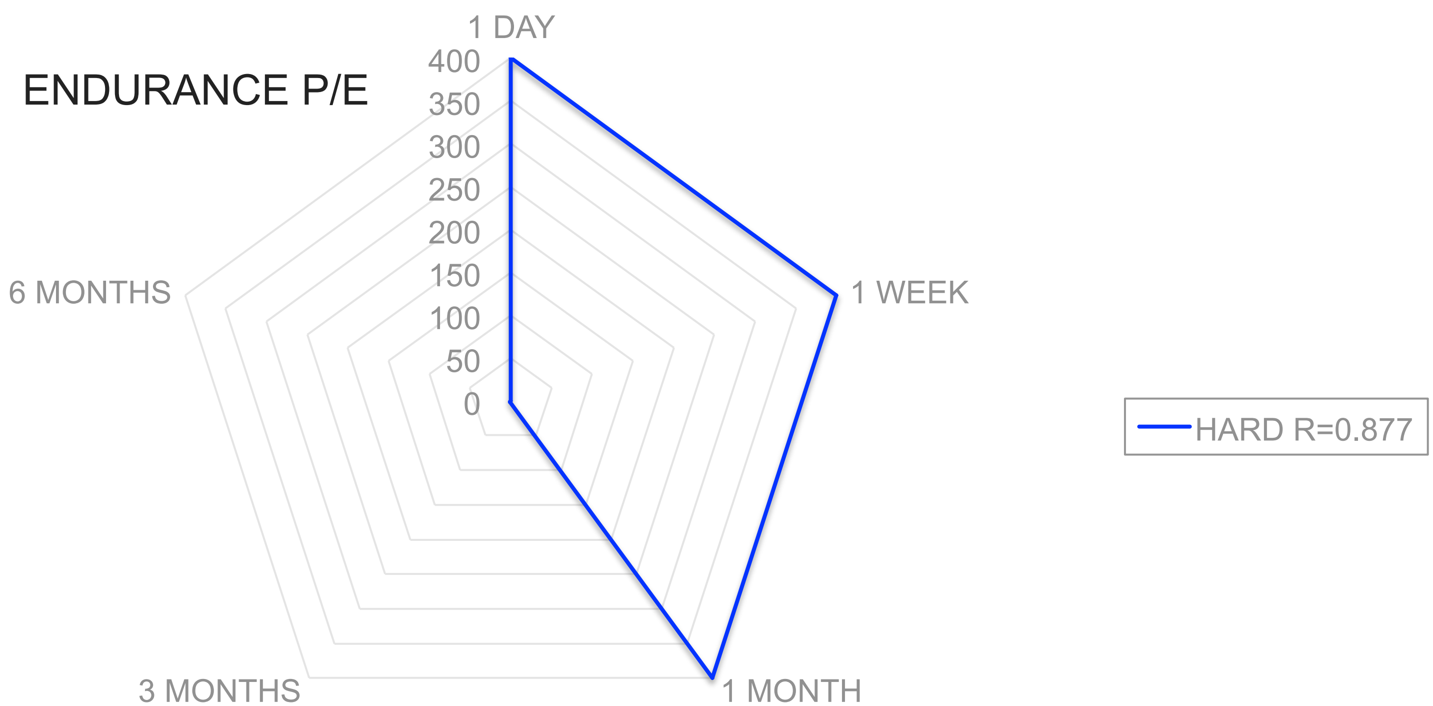
RELIBAILITY ESTIMATE FACTOR x1.75



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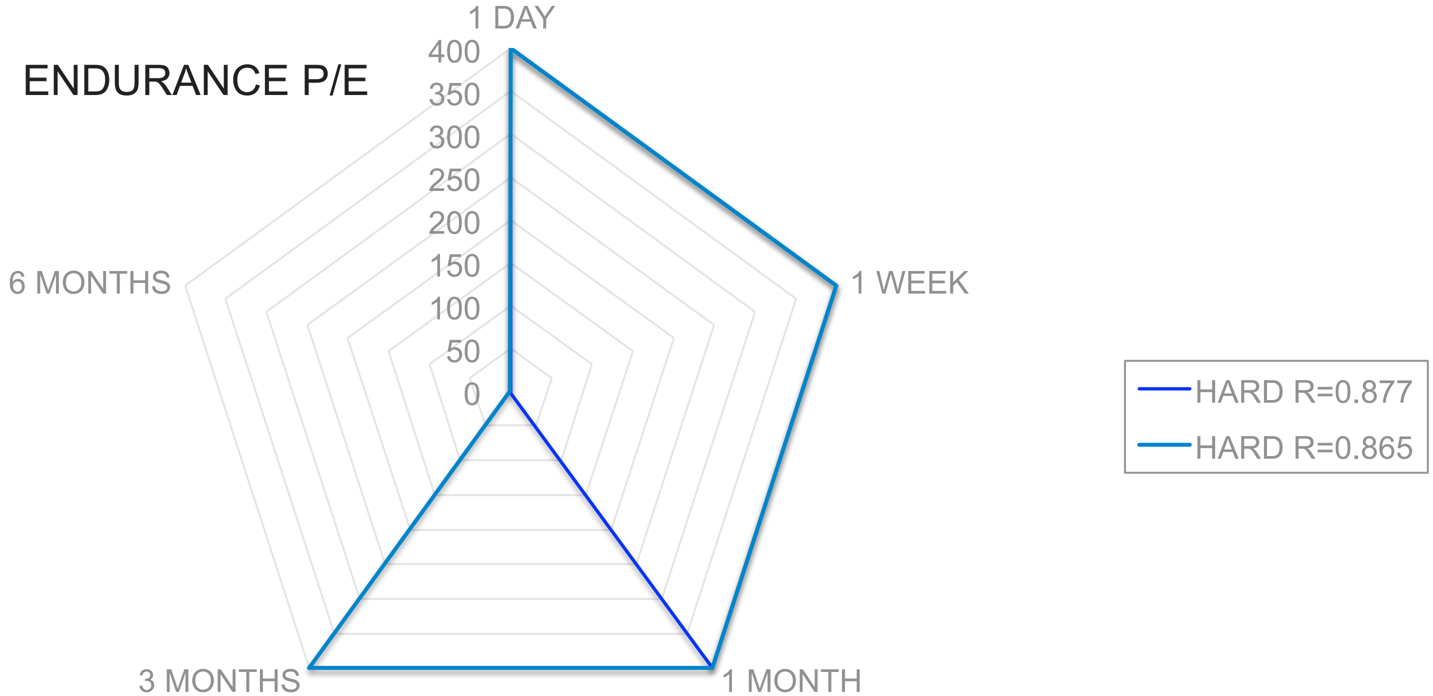
RELIBAILITY ESTIMATE FACTOR x1.75



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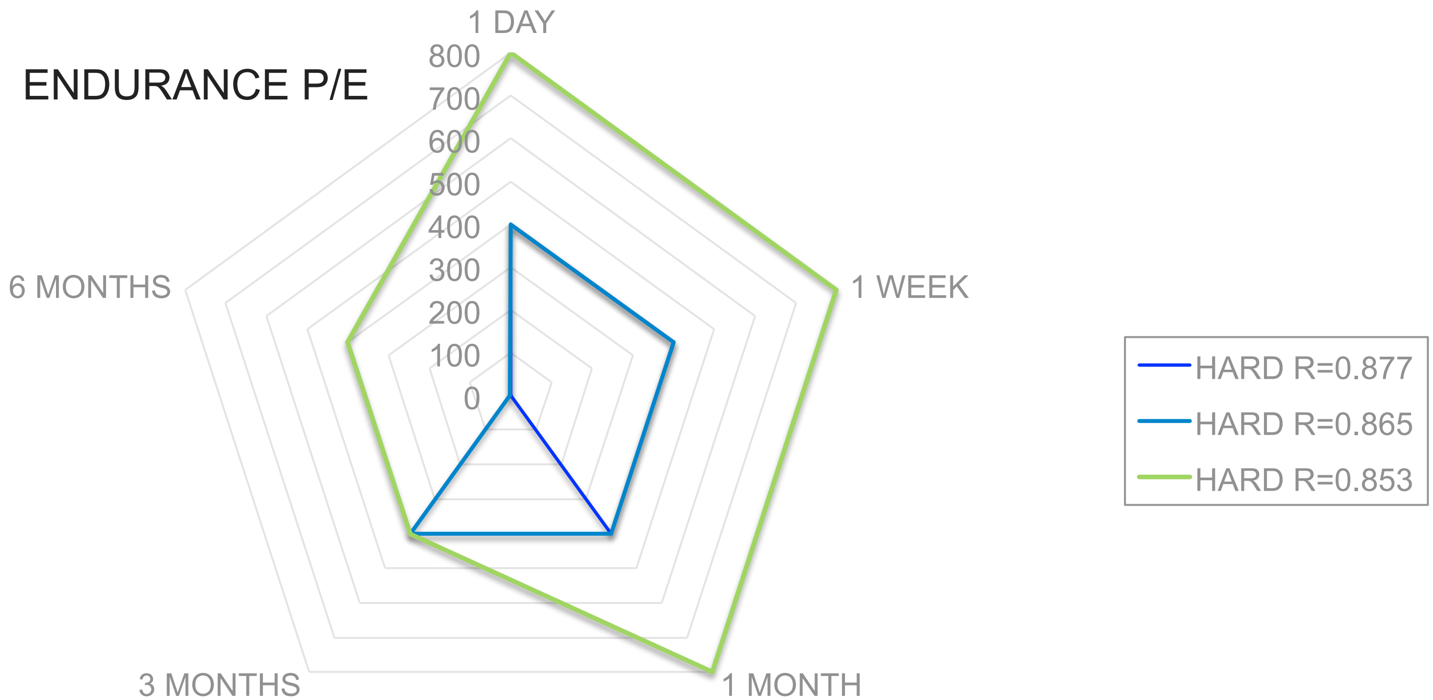
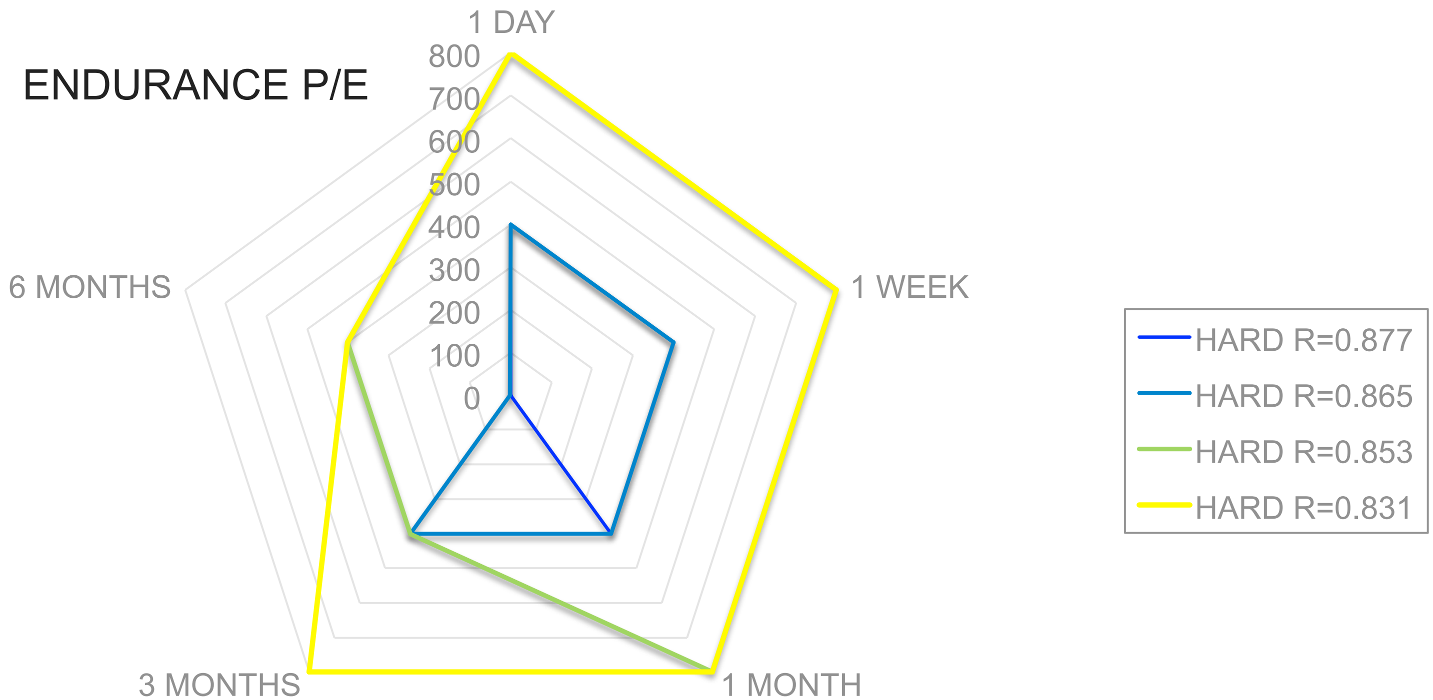
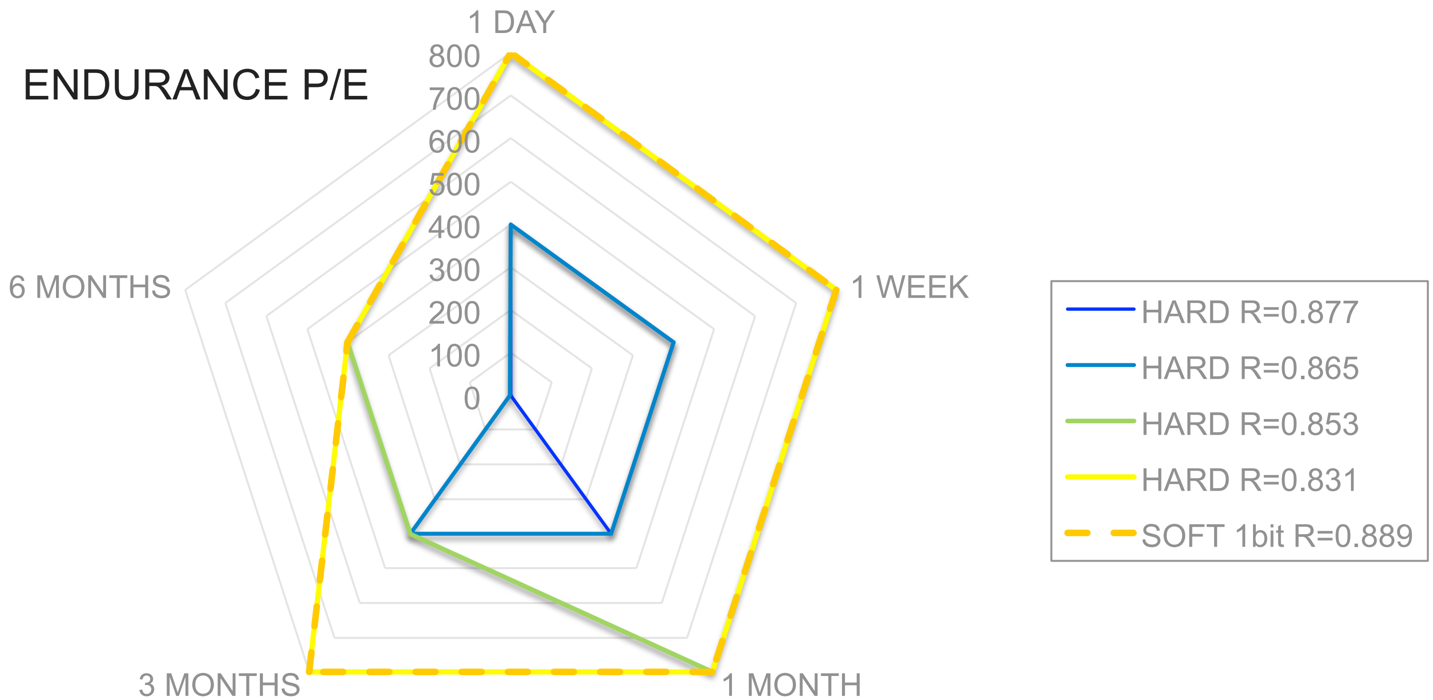
RELIBAILITY ESTIMATE FACTOR x1.75



RELIBAILITY ESTIMATE FACTOR x1.75



RELIBAILITY ESTIMATE FACTOR x1.75



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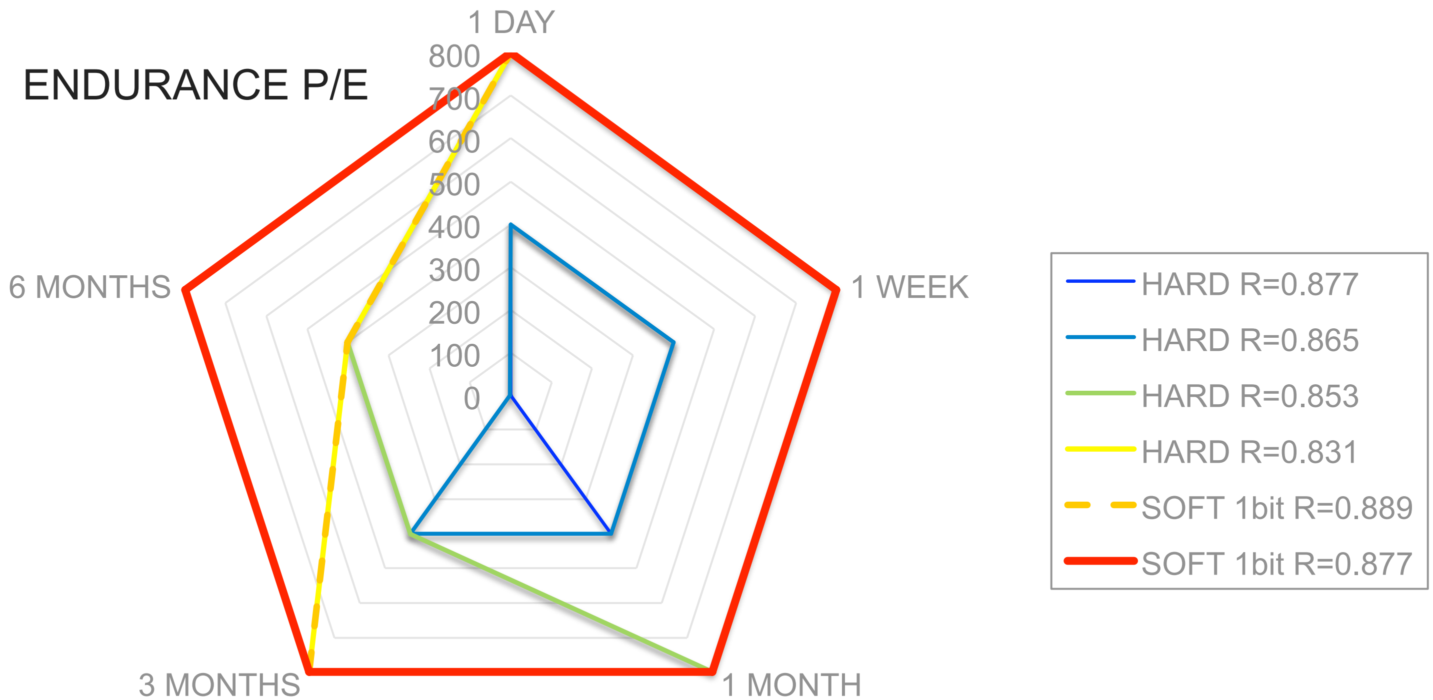
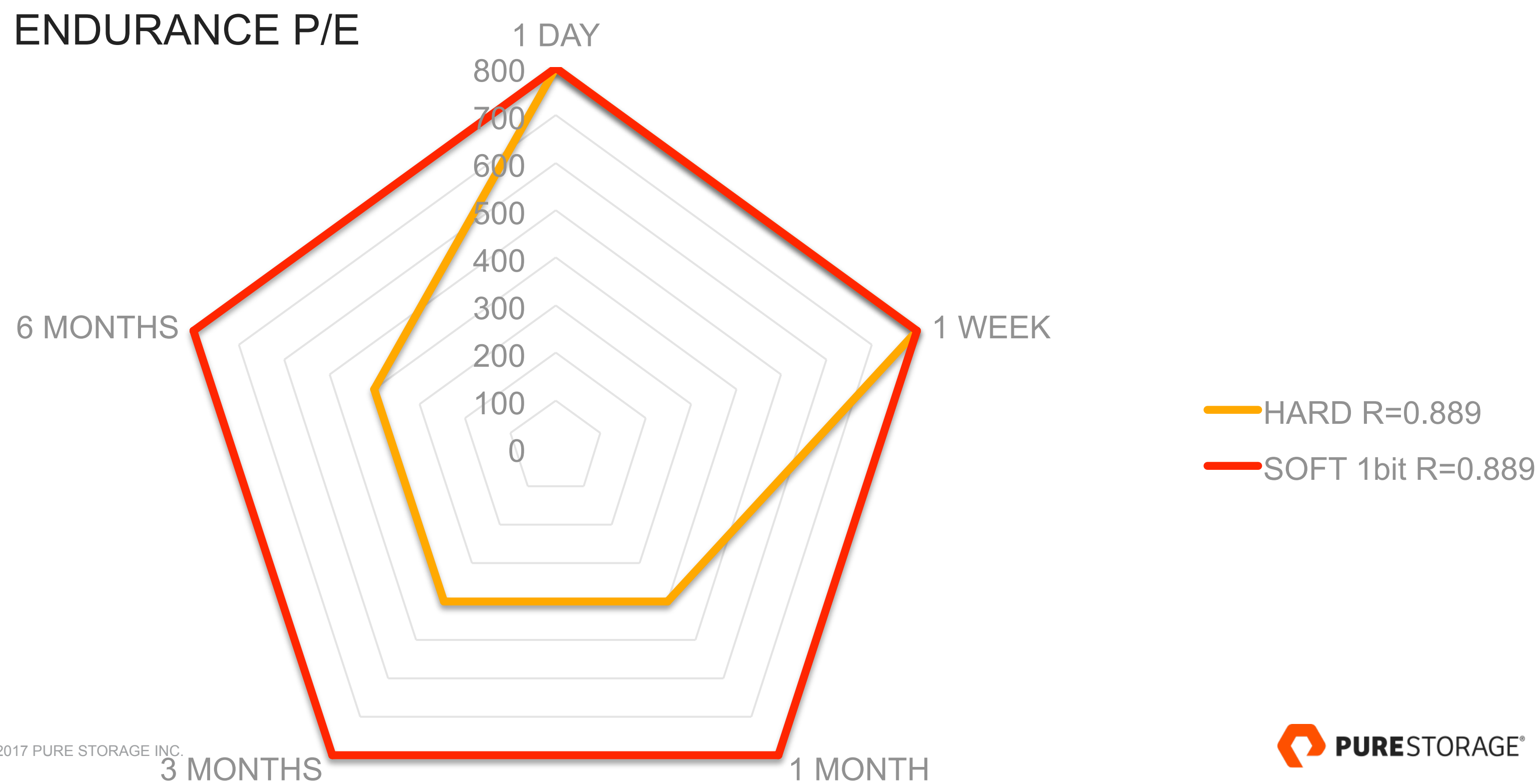
RELIBAILITY ESTIMATE FACTOR x1.75



RELIBAILITY ESTIMATE FACTOR x2.0



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CONCLUSION

– QLC NAND reliability of ~1K P/E and 3-6 months retention is feasible. BUT!

– Finding a good trade off between process improvements, programming time, read modes and required ECC is key for QLC success.

– Advanced read option features, soft read, are necessary to meet reliability targets of QLC.

– Designing QLC around soft read as the default read option would help reliability and relax constraints on process, program algorithm and erase algorithm.

– Large scale storage systems manages NAND so that data is always recoverable, therefore ability to retrieve data in timely manner is primary goal.

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Thank You

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