Intel® SSD 660p

Cost Benefit Analysis of QLC Flash

August 8, 2018

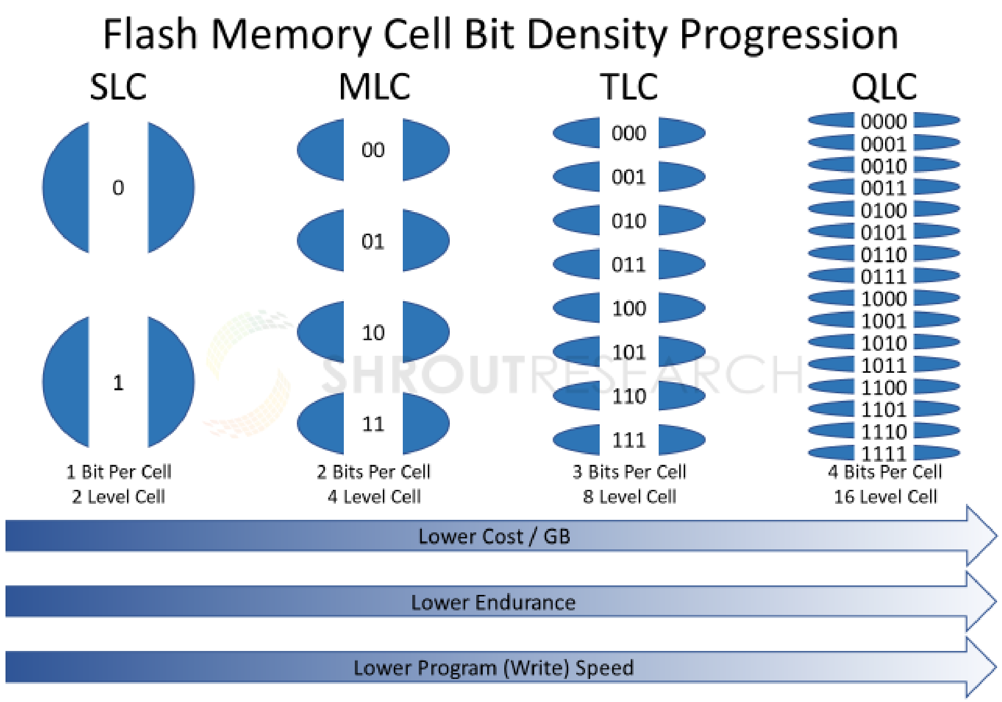
Version 1.1

Executive Summary

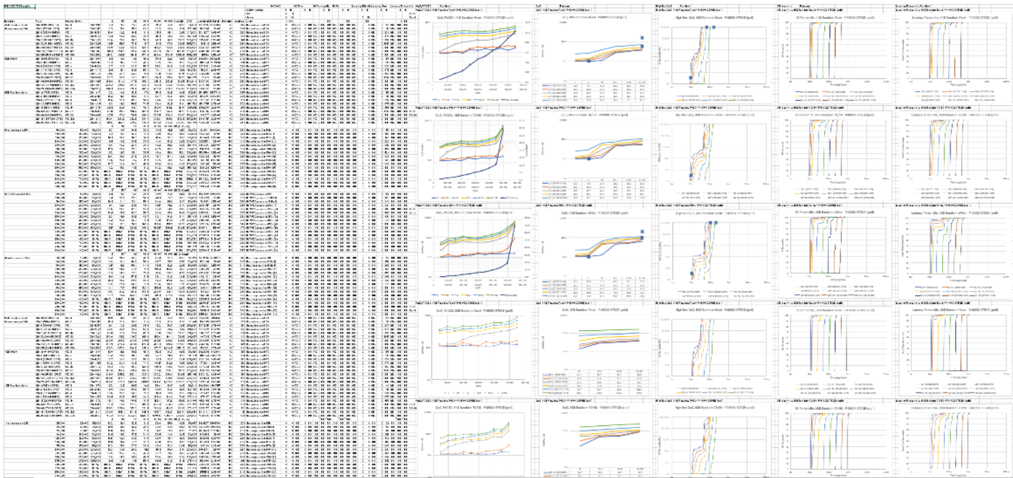
Solid State Drives offer responsiveness and throughputs unmatched by rotating media, but the persistent challenge has remained bringing the costs down far enough to spur greater adoption. SSDs came into the mainstream over a decade ago, and since then we have witnessed gradual increases in density in the form of process shrinks, a shift to multilayer 3D cell structures, and by increasing the number of bits stored per flash memory cell. With those advances come greater capacity products at reduced cost. While this progression is typically slow going, every once in a while a company comes along and shakes things up with a step change in either performance, capacity, or cost. The Intel® SSD 660p aims to take a shot at the latter while maintaining class-leading performance.

QLC Flash Memory

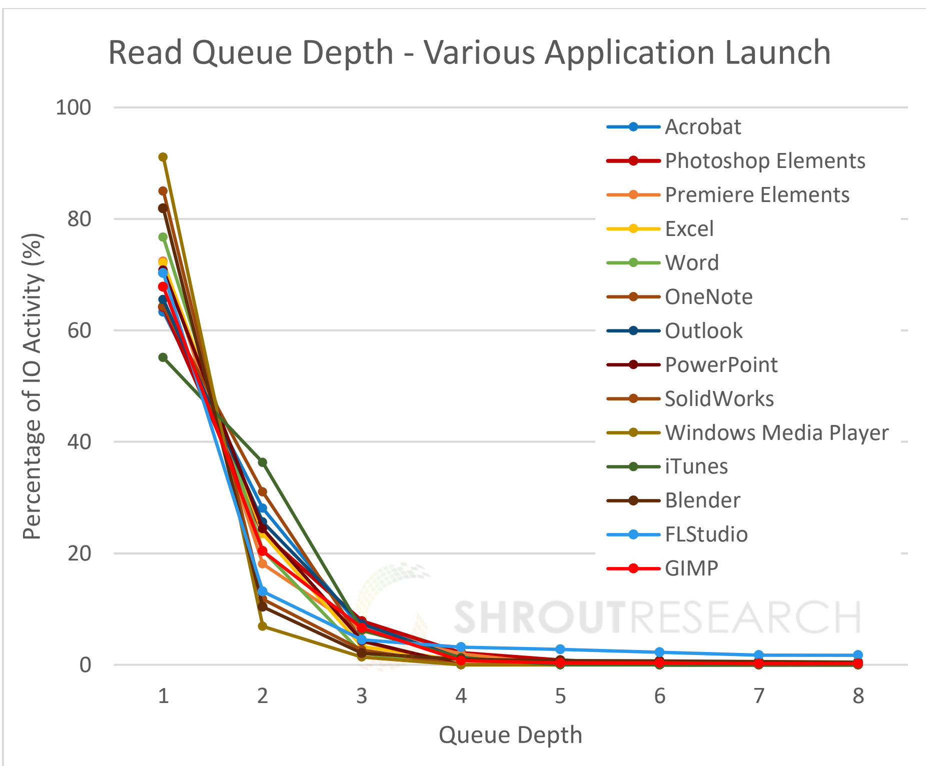
QLC flash memory would likely not be possible if not for some of the prior advances in flash technology. With 16 voltage states required to store four bits of data in a single cell, maintaining those states over time is helped by the cell volume and corresponding endurance gains that came with the move to 3D NAND. These and some additional factors have now culminated in QLC media capable of endurance sufficient for mainstream client PC usage. One additional hurdle to overcome is that flash memory cells with 16 states must be programmed with greater precision and therefore more slowly. Improved dynamic SLC caching techniques can effectively mitigate this issue and will be covered later in this paper.



Shrout Research S-PASS Testing

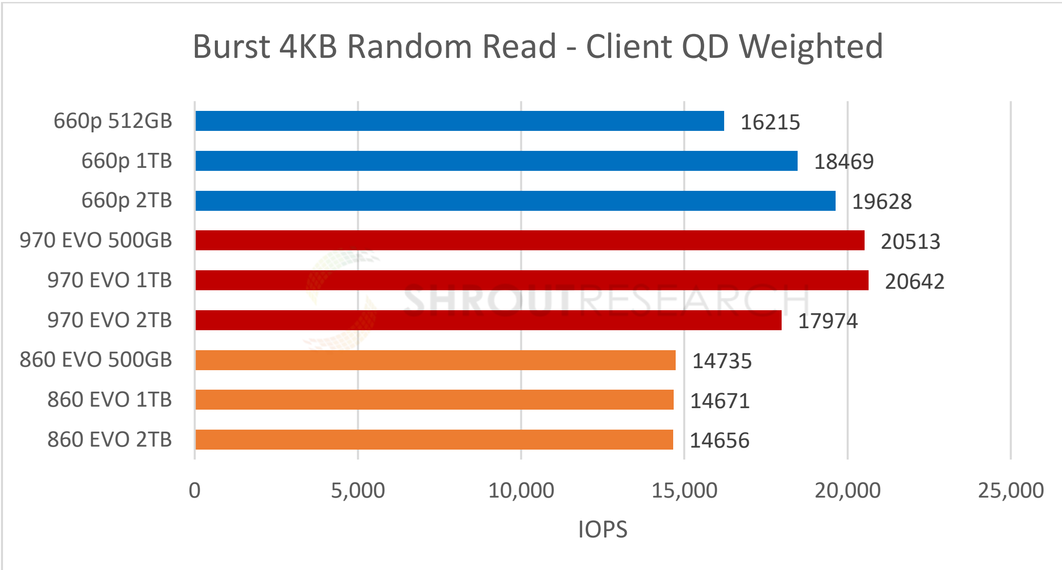


The Shrout Research Storage Performance Analysis Software Suite (S-PASS) is an in-house developed tool set that ensures realistic conditioning of the storage device under test. Workload application granularity is superior to that of any off the shelf benchmark tool. Precise I/O-level latency telemetry enables tracking of instantaneous throughput and IOPS of even the shortest of workload bursts.

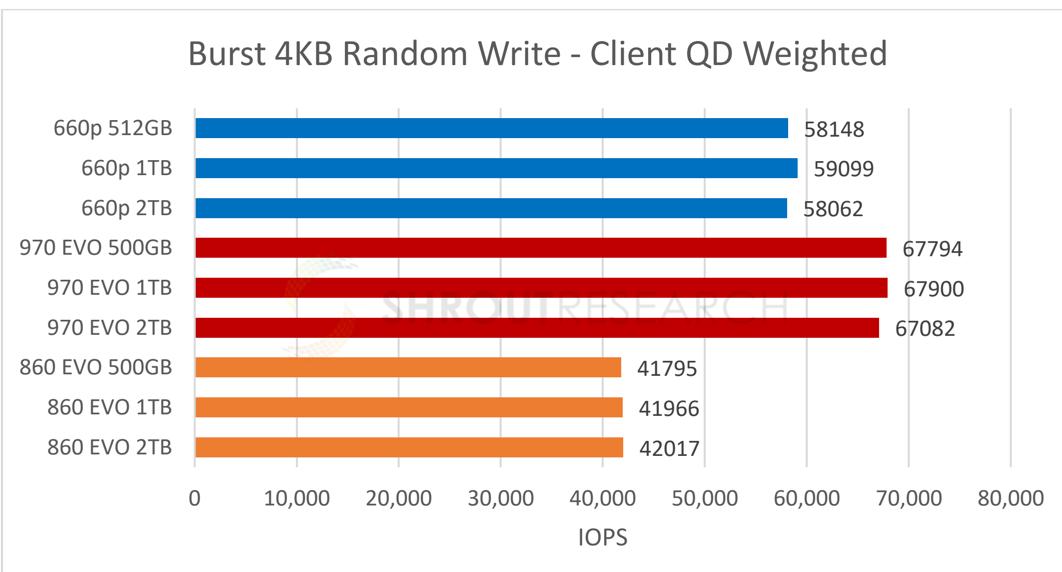


S-PASS 'Client QD Weighted' results account for the Queue Depths observed in the most commonly used applications.

S-PASS Random Workload Performance

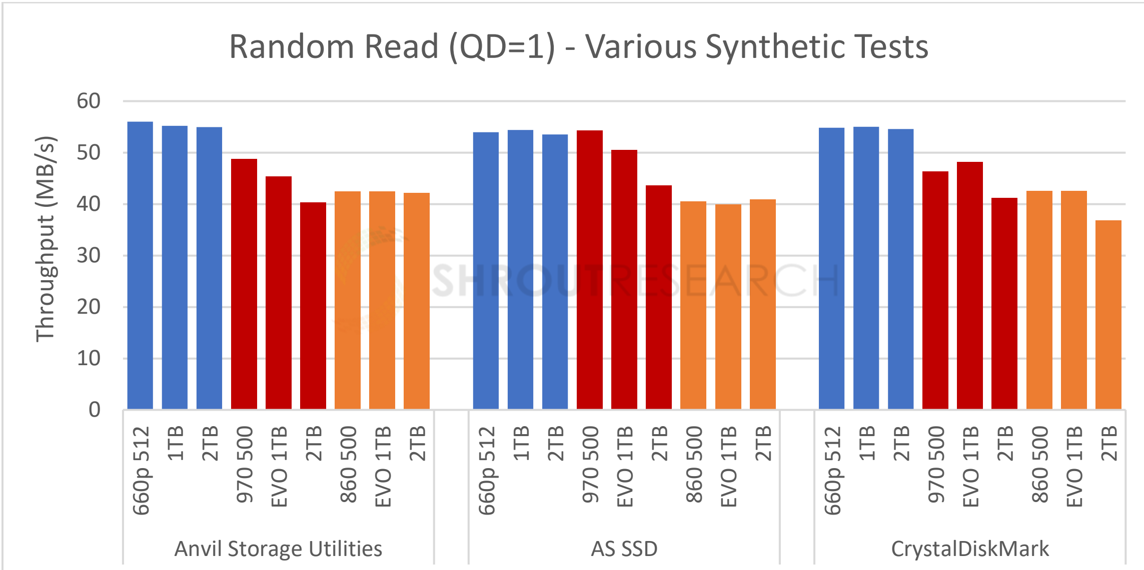


The S-PASS random workload test weighs results based on the Queue Depths commonly observed in client system usage (shown earlier in this paper). In these results, we find the Intel® SSD 660p to offer competitive performance which steadily climbs through the higher capacity tiers.

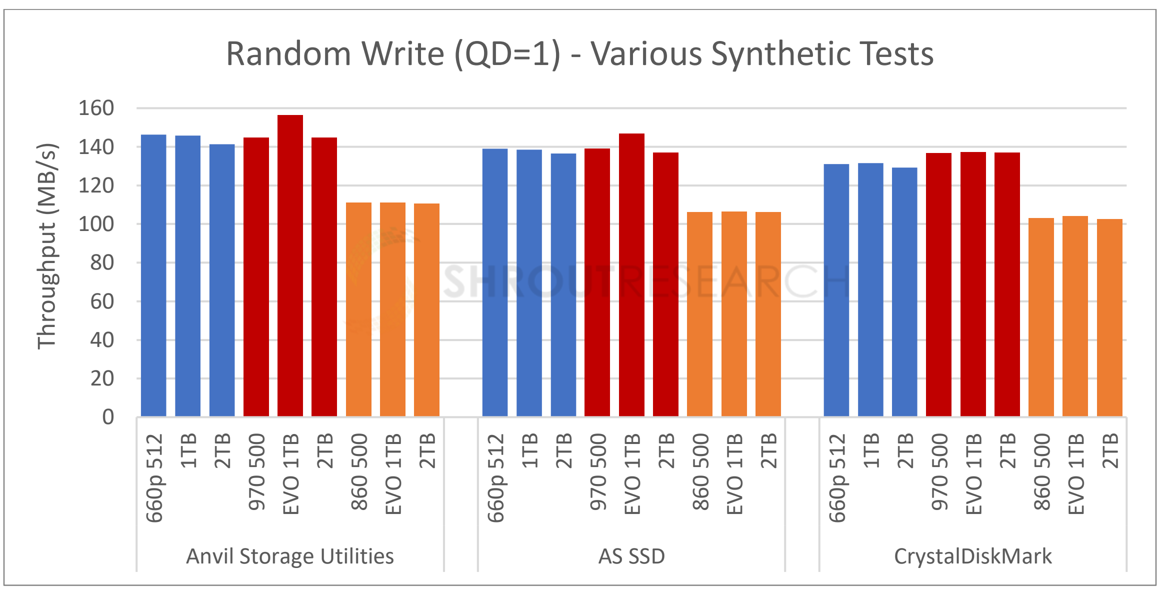


While random writes are less frequently seen on client systems, it is vital that any SSD service them quickly when they do occur. The use of a large SLC cache enables the Inel® SSD 660p to remain well within the NVMe performance class, exceeding SATA performance by a comfortable margin.

Random Workload Performance – Synthetic Tests

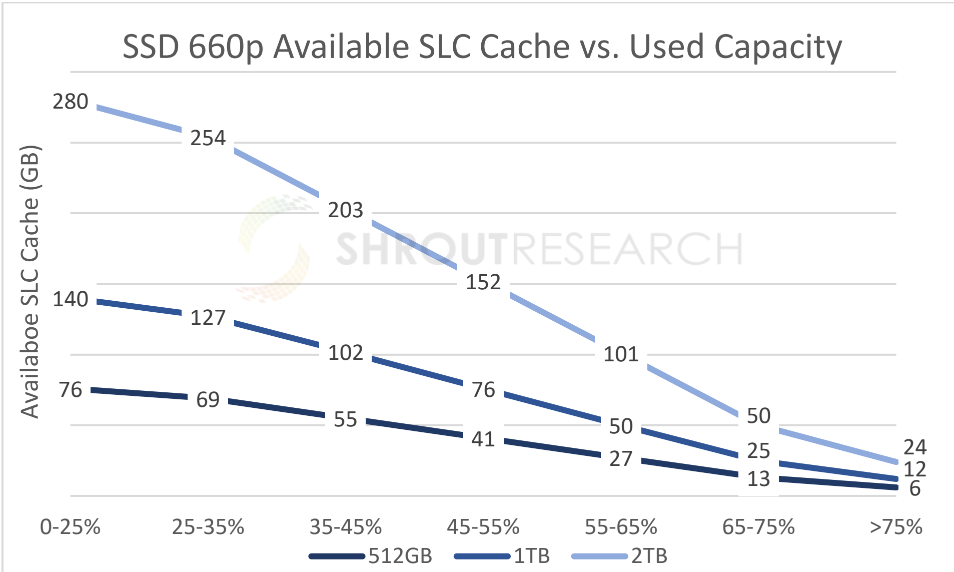


In a range of synthetic benchmarks run across competing products, the Intel® SSD 660p offers superior low Queue Depth Random Read performance. This metric is most important when determining system responsiveness and contributes greatly to how the speed of a given system is perceived by the user.



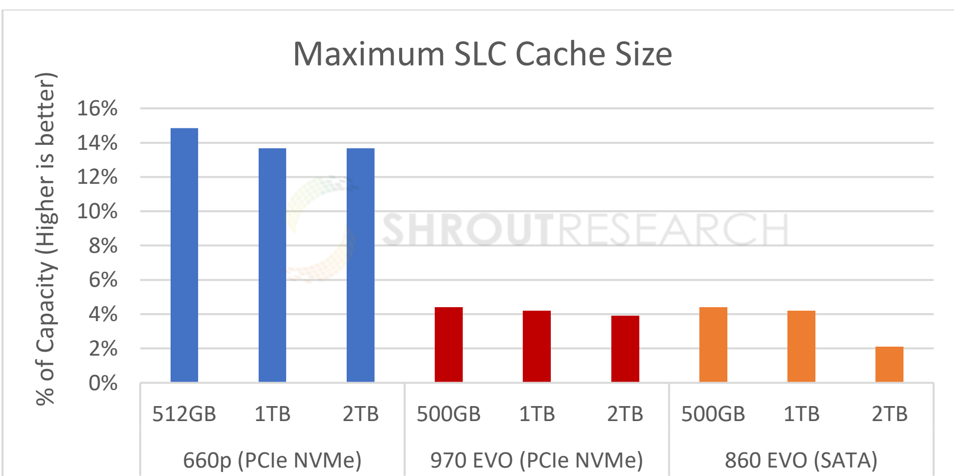
In random writes, SLC caching helps the QLC-based Intel® SSD 660p remain competitive with top-tier TLC SSDs.

Mitigating QLC Write Speeds – A Larger SLC Cache

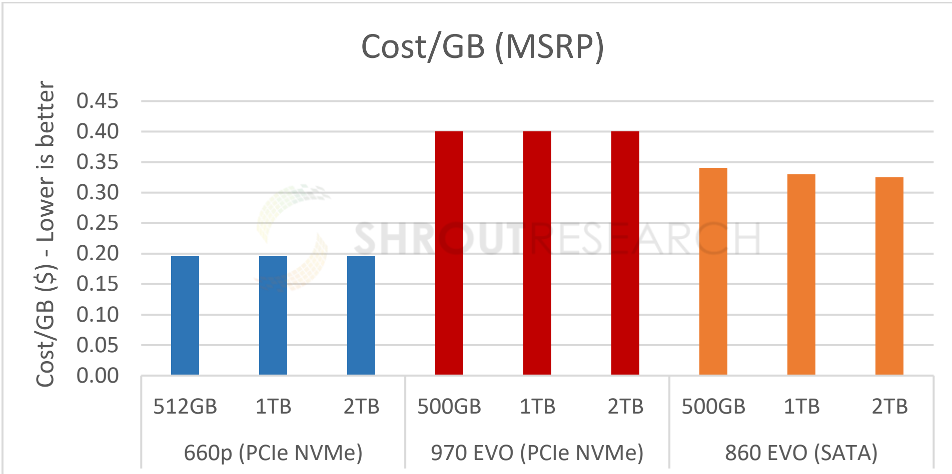


Given that QLC SSDs have a slower sustained write speed vs. TLC, it was important to reduce the likelihood of depleting the SLC cache. Intel accomplished this by starting with a generous static cache and increasing the maximum dynamic cache to approximately 14% of the total drive capacity. Assuming the capacity purchased is loosely proportional to the size of any anticipated user bulk write events, typical client usage of the Intel® SSD 660p will rarely, if ever, see its cache reach a fully depleted state.

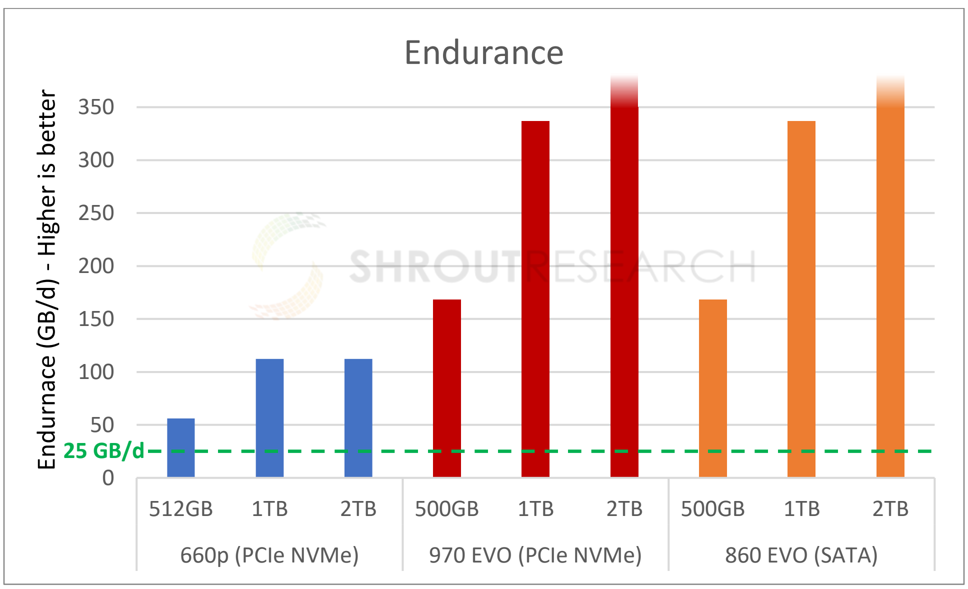
Cache depletion requires not only that the user write the amounts noted in the above chart, but those writes would need to saturate the SLC write speeds of the destination SSD. It is highly unlikely that a user would have a data source capable of >1GB/s throughputs, and writes from slower sources are countered by the background SLC->QLC folding rate of the drive, meaning the cache would remain effective for larger total writes than noted above.



Cost/Benefit Analysis and Endurance



Storing 33% more data per cell can enable radical reductions in cost/GB as seen above. This is even more significant when considering that typical user experience should be on parity with products retailing at 2x the cost.



QLC requires tighter cell voltage thresholds when compared with TLC, which translates to lower endurance. The Intel® SSD 660p uses of a larger dynamic SLC cache also comes at a slight cost since SLC block erasures wear the same cells that may be later transitioned to QLC, effectively amplifying cell wear. Despite these detractors, one must consider that typical client usage falls far below typical TLC SSD endurance ratings. To cite an extreme example – a complete Windows 10 installation, including all necessary drivers and several productivity tools (including Office 2016) totals less than 25GB of drive writes. A user could reinstall their OS daily for five years and still not exceed the Intel® SSD 660p endurance rating.

Summary

The innovation of QLC flash with integration of a dynamic SLC cache provides NVMe-class performance that easily surpasses traditional SATA storage in our testing. Looking at random write results, SLC caching helps the QLC-based Intel® SSD 660p remain competitive with top-tier TLC drives yet the integration allows for dynamic adjustment of cache size based on utilized capacity. Synthetic benchmarks tested across competing products show the Intel® SSD 660p offers similar low queue depth random read performance to TLC products. Endurance of QLC flash provides substantial headroom for consumer workloads and buyers could reinstall their OS daily for five years and not exceed the Intel® SSD 660p endurance rating. In a highly competitive SSD market QLC flash and the Intel® SSD 660p provide a unique combination of performance and cost efficiency.

Author: Allyn Malventano, Technology Analyst at [Shrout Research]

Editor: Ryan Shrout, President and Principal Analyst at [Shrout Research]

Please direct questions about this paper to allyn@shroutresearch.com.

Disclosure: This paper was commissioned by Intel. All testing, evaluation and analysis was performed in-house by Shrout Research and its contractors. Shrout Research provides consulting and research services for many companies in the technology field, others of which may be mentioned in this work.

Appendix

The following test system configuration were used in the preparation of this paper:

	Product / Version
Motherboard	ASUS STRIX Z370-E Gaming (BIOS 0805)
CPU	Intel® Core™ i7-8700K
RAM	16GB DDR4-2400
GPU	NVIDIA GeForce GTX 1080
OS	Windows 10 Pro RS4 (1803)
Storage	Intel® SSD 660p Samsung 970 EVO Samsung 860 EVO

Tests document performance of components on a particular test, in a specific system. Differences in hardware, software, or configuration will affect actual performance. Consult other sources of information to evaluate performance as you consider your purchase.