White Paper

Performance Consistency

SanDIsk Corporation | Corporate Headquarters | 951 SanDisk Drive, Milpitas, CA 95035, U.S.A.
Phone +1.408.801.1000 | Fax +1.408.801.8657 | www.SanDisk.com

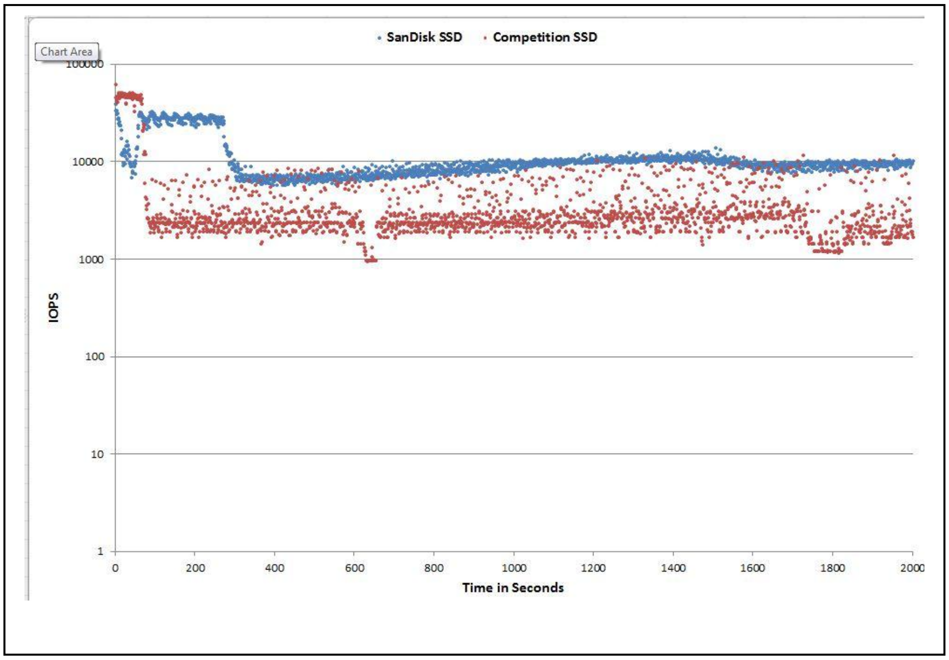
Table of Contents

1. Executive Summary

Measuring SSD performance using average MB/s, IOPS, and latency shows only part of an SSD's performance capabilities. Such measurements do not reveal other performance aspects that may negatively impact some applications. SSD performance consistency over time is an important factor that should be considered as part of the overall SSD performance capabilities. In the beginning, users may enjoy strong application performance and responsiveness. However, application performance and/or responsiveness may be degraded over time and in some cases may lead to application failure if SSDs with bad performance consistency are used.

This document describes what SSD performance consistency is and provides results from tests performed on SanDisk SSD products that illustrate performance consistency when compared to other vendors' offerings. An example is shown in the graph below:

The graph illustrates 4KB random writes after the drive has been sequentially preconditioned with 128KB writes. As will be explained in this document, scattered dots indicate poor consistency.



2. Consistent Performance – Overview

SSD performance measurements are commonly done using average values for the measured time period: average throughput (MB/s), average IOPS, and average IO latency. In a few cases, such as IO MAX Latency, the measurements are done by showing the highest value grade. So far, these measurements are widely used and generally accepted as a standard approach to determining the performance differences between different SSDs. However, with the introduction of the latest generation of SSD technology, it became obvious that most vendors' SSDs, using these traditional measurements, will show overall strong and similar performance results. As a result, additional measurements are needed to differentiate performance between vendors.

Performance average values show the SSD overall performance and if they are within highest, medium, or lowest on the performance scale. They do not show the SSD performance steadiness over the measured time. While the average can be relatively high for an SSD, in reality there can be big variations between high and low performance over the measured time. Many applications are sensitive to poor performance consistency, which tends to impact those applications negatively and poorly impacts the user experience. Occasional long latency of an IO or a short period of ultra-slow performance can appear as a hiccup in an application; in the worst case it can lead to the application timing out. In other words, the SSD performance consistency is an important factor to be considered as well.

2.1 Behind the Scene – SSD Performance Consistency

There are multiple ways to look at performance consistency, either quantitatively or qualitatively. One quantitative way of defining performance consistency may be to examine the ratio of the maximum IO latency to the average latency; the smaller the ratio, the more consistently the drive is performing. In terms of taking a qualitative approach for viewing performance consistency, we adopt a methodology also used by some online reviewers[1] that measures the IOPS of a given workload for a given period of time. From the measured results, a plot of the IOPS of each second within the measurement period is created – the IOPS of each second is represented as a single dot on the chart. The amount of scattered dots visually and qualitatively depicts the drive's performance consistency.

While the performance consistency of an SSD can be examined for any type of workload, the most challenging workload for an SSD to produce consistent performance is one in which it has to handle a lot of small writes. This is because of the way NAND cache works to conduct data writes. This is the type of workload that we will focus on in this white paper.

[1] http://www.anandtech.com/show/6433/intel-ssd-dc-s3700-200gb-review/3

With flash memory, updating existing data is done by marking the old data as invalid and writing the updated data to another free physical location. However, the old data physical location is not free for use. Over time, the availability of the SSD free physical location decreases. Reclaiming physical locations currently with invalid data is done using a mechanism known as "garbage collection."

However, the garbage collection mechanism results in a penalty on performance while running. An SSD that can balance properly between processing continually incoming IO writes and the garbage collection mechanism will show better performance consistency than devices with poor balance between these two tasks.

2.1.1 Tools and Platform

While any tool that can generate user defined workloads can be used to produce the data needed for consistency analysis, SanDisk chose to use IOMeter, a commonly used tool in the industry. Similarly, while any test platform can be used, SanDisk used a machine with an Intel Z77 chipset, Intel® i7-3770 3.4GHz CPU, and 8GB of DRAM. The test device is connected to the machine's SATA-3 port, with Windows® 8 serving as the operating system and using the Intel iRST 11.7.0.1013 driver.

2.1.2 Examples

The following chart is an example of an SSD with good performance consistency. The more crowded the dots (representing performance measurements at a certain point in time) and closer the dots are to each other the better the performance consistency. The chart for an ideal drive with 100% performance consistency would show just one thin line.

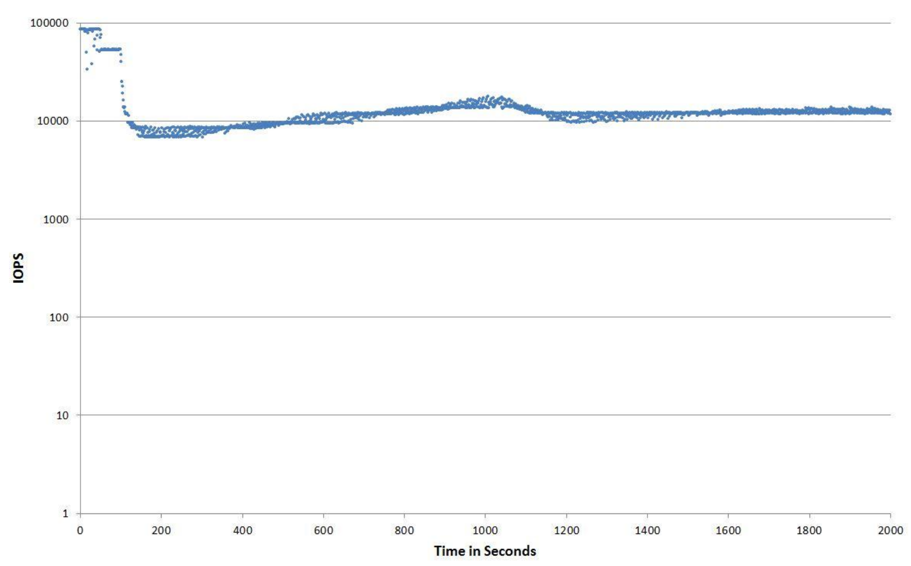


Figure 1: Random Write 4K 32QD – An Example of Good Performance Consistency

Note: Performance consistency is judged by looking at the variation in performance (scattering of dots) only within a narrow window of time, such as tens of seconds. The difference in the level of performance at two very different points in time, such as 50 seconds and 600 seconds in Figure 1, is not to be compared for this purpose. The much higher performance at 50 seconds in this example is part of initial burst performance due to the availability of free blocks from overprovisioning, and the performance at 600 seconds is the drive's steady state performance when garbage collection is deployed.

The following chart is an example of an SSD with poor performance consistency. Notice how the dots are widely scattered over a huge performance range during the entire measurement period.

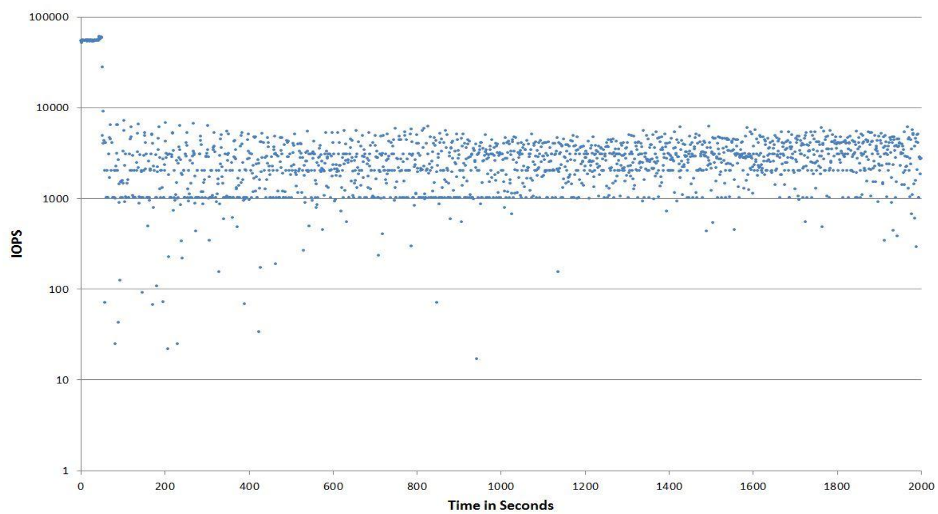


Figure 2: Random Write 4K 32QD – An Example of Poor Performance Consistency

The next section demonstrates how well SanDisk SSD products performance consistency conducts under random write workload.

3. SanDisk SSD – Consistent Performance

3.1 Overview

In the following sections we will show SanDisk SSD products' consistent performance using two types of views: Overall and Steady state zoom-in.

The Overall view is an overview chart showing the overall SSD performance consistency from the start of the measurements to the end of the measurements. A logarithmic scale for the y-axis is used for this view.

The Steady state zoom-in view is focused on the steady state portion of the measurements. A linear scale for the y-axis is used for this view.

The following measurements were taken using the following test setup:

- Precondition – Sequential Write 128KB 32QD going over the SSD capacity twice
- Workload – Random Write 4KB 32QD for 2000 seconds

3.1.1 Consistent Performance – Overall View

SanDisk Extreme® II SSD 240GB

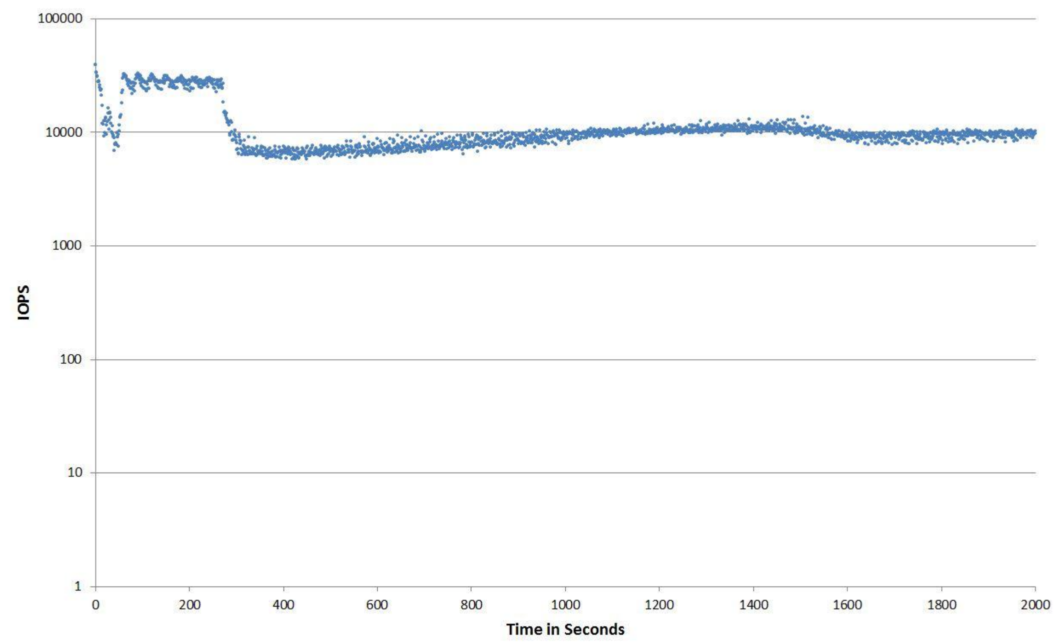


Figure 3: SanDisk Extreme II SSD

In the first 260 seconds there are plenty of free physical locations thanks to the 7% overprovision so the firmware can focus mostly on processing the incoming IO writes, hence the high performance. Once the available free physical locations are depleted below a certain threshold, the garbage collection mechanism starts to work which has some overhead and thus the performance decreases. Over time the two tasks of processing incoming IO writes and garbage collection is balanced properly, the performance is stabilized and the performance consistency is optimal.

SanDisk X110 SSD 256GB

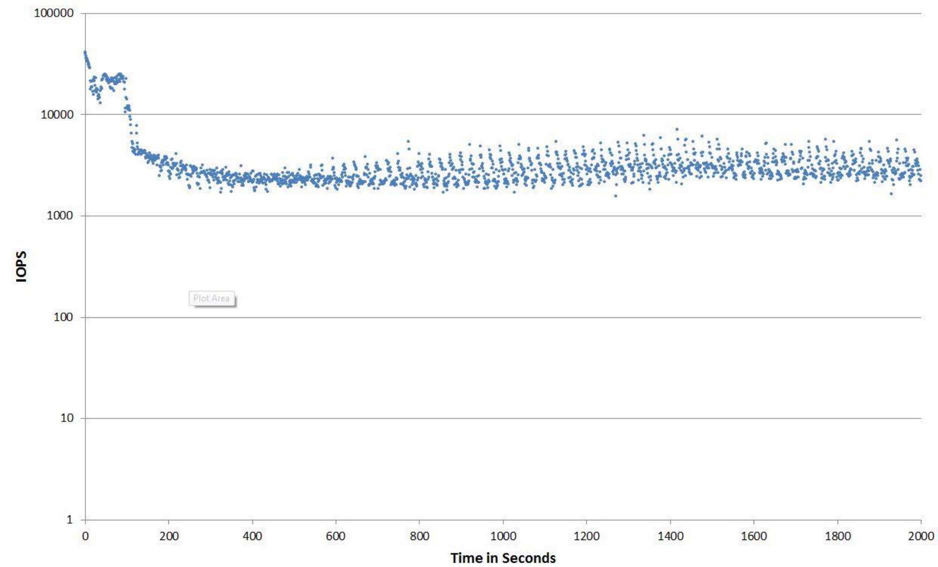


Figure 4: SanDisk X110 SSD

Due to a smaller percentage of overprovision, the high performance at the beginning starts to decrease earlier (after 80 seconds). Once the available free physical locations are below a certain threshold, the garbage collection mechanism starts to work, which includes some overhead. Over time the two tasks of processing incoming IO writes and garbage collection is balanced properly, leading to good performance consistency. However, the firmware has to give a little more attention to the garbage collection mechanism. This explains the differences between the SanDisk Extreme II SSD and the SanDisk X110 SSD performance consistency.

3.1.2 Consistent Performance – Steady State Zoom-in View

SanDisk Extreme II SSD 240GB

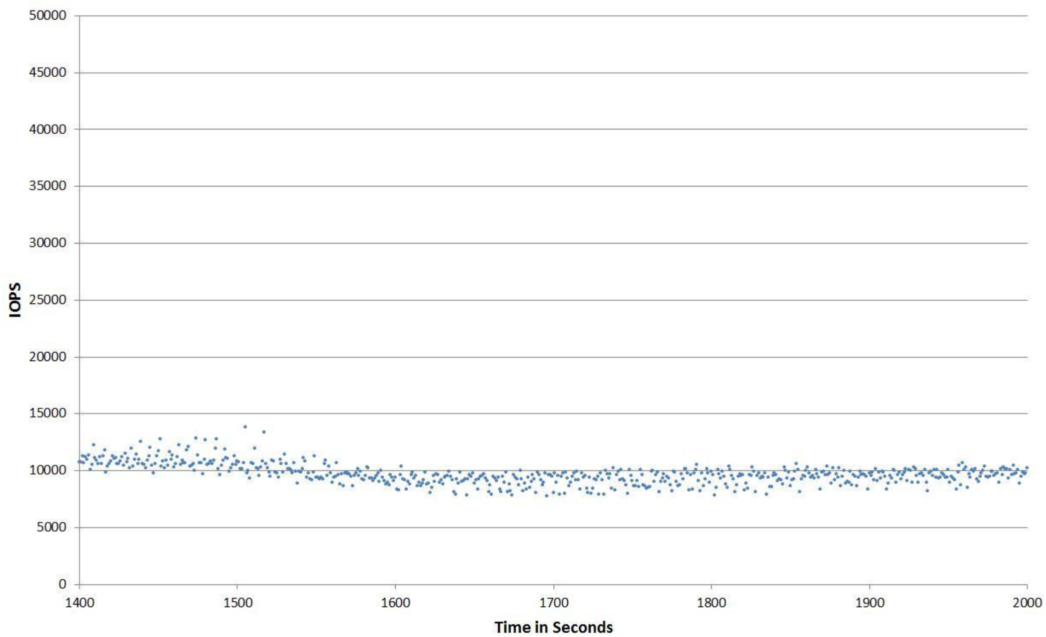


Figure 5: SanDisk Extreme II SSD

Zooming into the steady state portion for the SanDisk Extreme II SSD, the differences between the low and high performance points are small due to the excellent balance between processing incoming IO writes and garbage collection.

SanDisk X110 SSD 256GB

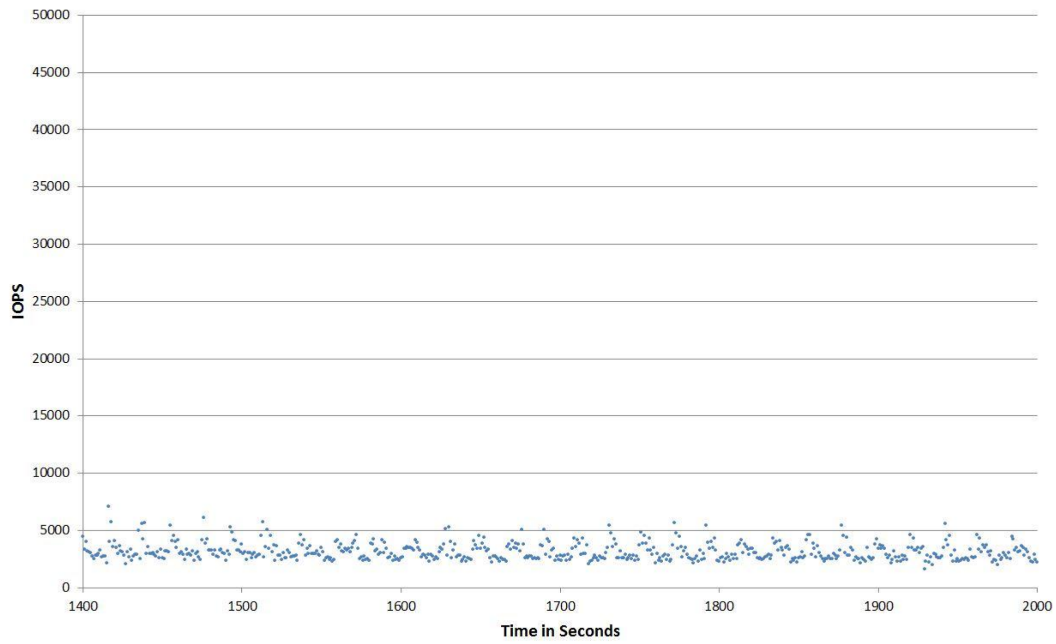


Figure 6: SanDisk X110 SSD

Zooming into the steady state portion for the SanDisk X110, the differences between the low and high performance points are still relatively small due to the good balance between processing incoming IO writes and garbage collection.

Overall while the SanDisk X110 SSD performance is lower than that of the SanDisk Extreme II SSD, both products' performance consistency is optimal.

Summary

SSD performance consistency is an important factor that demonstrates an SSD's performance stability over time, which in turn impacts application stability. SSD performance consistency should be part of the overall SSD performance assessment along with average grades of MB/s, IOPS, and IO latency. SanDisk SSD products demonstrate very good performance consistency thanks to proper balance between processing incoming IO writes and the garbage collection mechanism.

Appendix A – SanDisk SSD vs. Competitors

SanDisk SSDs' superior random write performance consistency also stands out when compared to the other SSDs. Here the random write performance consistency comparison between SanDisk SSDs and some of its competitors is shown.

The measurements were taken using the following test setup:

- Precondition – Sequential Write 128KB 32QD going over the SSD capacity twice
- Workload – Random Write 4KB 32QD for 2000 seconds

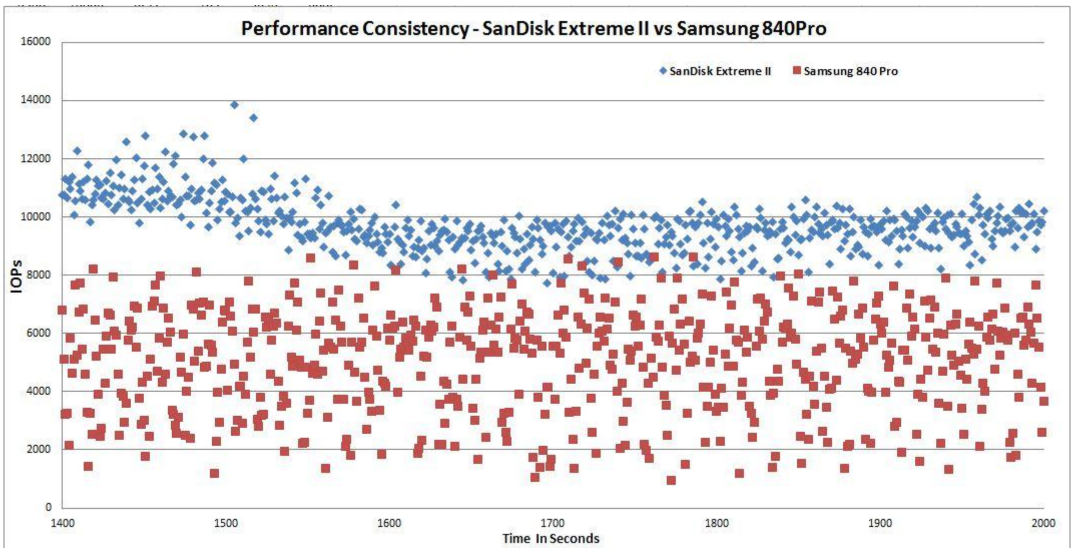


Figure 7: SanDisk Extreme II SSD vs. Samsung 840Pro

The range of variation between the lower performance points and the higher performance points is much smaller for the SanDisk Extreme II SSD (~3000 IOPs) compared to the Samsung 840Pro (~7000 IOPs).

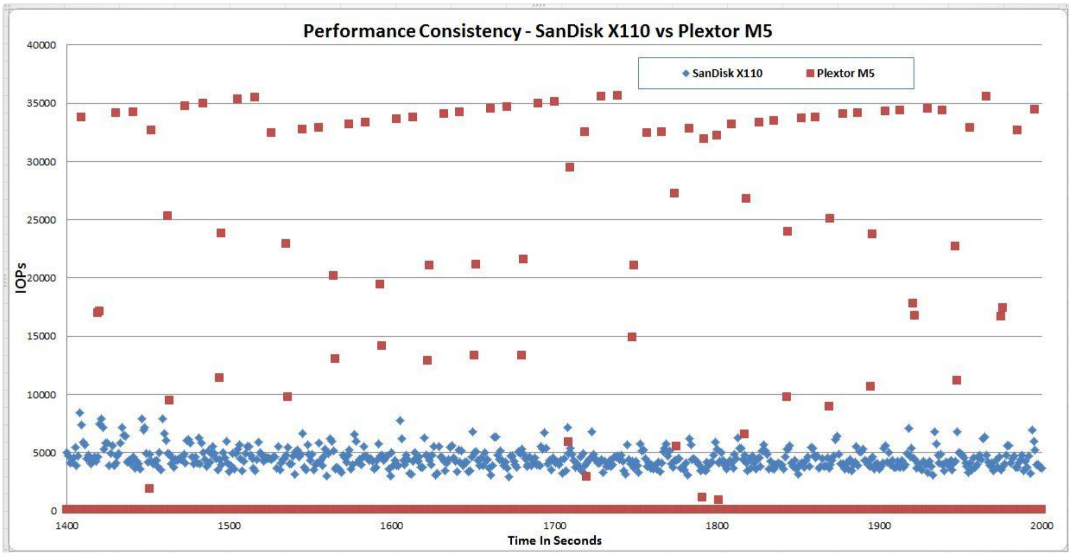


Figure 8: SanDisk X110 SSD vs. Plextor M5

The range of variation between the lower performance points and the higher performance points is much smaller for the SanDisk X110 SSD (~4000 IOPs) compared to the Plextor M5 (~35000 IOPs).

Important Notice

Products, samples and prototypes are subject to update and change for technological and manufacturing purposes.

SanDisk Corporation general policy does not recommend the use of its products in life support applications wherein a failure or malfunction of the product may directly threaten life or injury. Without limitation to the foregoing, SanDisk shall not be liable for any loss, injury or damage caused by use of its products in any of the following applications:

- Special applications such as military related equipment, nuclear reactor control, and aerospace
- Control devices for automotive vehicles, train, ship and traffic equipment
- Safety system for disaster prevention and crime prevention
- Medical-related equipment including medical measurement device

Accordingly, in any use of SanDisk products in life support systems or other applications where failure could cause damage, injury or loss of life, the products should only be incorporated in systems designed with appropriate redundancy, fault tolerant or back-up features. Per SanDisk Terms and Conditions of Sale, the user of SanDisk products in life support or other such applications assumes all risk of such use and agrees to indemnify, defend and hold harmless SanDisk Corporation and its affiliates against all damages.

Security safeguards, by their nature, are capable of circumvention. SanDisk cannot, and does not, guarantee that data will not be accessed by unauthorized persons, and SanDisk disclaims any warranties to that effect to the fullest extent permitted by law.

This document and related material is for information use only and is subject to change without prior notice. SanDisk Corporation assumes no responsibility for any errors that may appear in this document or related material, nor for any damages or claims resulting from the furnishing, performance or use of this document or related material. SanDisk Corporation explicitly disclaims any express and implied warranties and indemnities of any kind that may or could be associated with this document and related material, and any user of this document or related material agrees to such disclaimer as a precondition to receipt and usage hereof. EACH USER OF THIS DOCUMENT EXPRESSLY WAIVES ALL GUARANTIES AND WARRANTIES OF ANY KIND ASSOCIATED WITH THIS DOCUMENT AND/OR RELATED MATERIALS, WHETHER EXPRESS OR IMPLIED, INCLUDING WITHOUT LIMITATION, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR INFRINGEMENT, TOGETHER WITH ANY LIABILITY OF SANDISK CORPORATION AND ITS AFFILIATES UNDER ANY CONTRACT, NEGLIGENCE, STRICT LIABILITY OR OTHER LEGAL OR EQUITABLE THEORY FOR LOSS