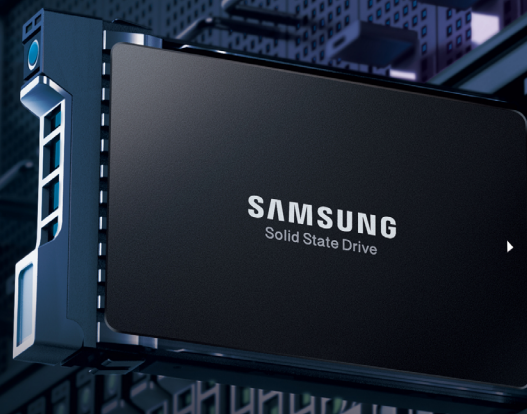


Over-Provisioning Benefits for Samsung Data Center SSDs

Over-provisioning is a function that provides additional capacity specifically for data to be erased from an SSD, without interrupting system performance. The dedicated over-provisioning space may be adjusted to the user's preference, delivering benefits that include faster speed and longer SSD life. This white paper provides in-depth information about over-provisioning, as well as instructions on how to adjust the over-provisioning space, and considerations to be made before doing so.

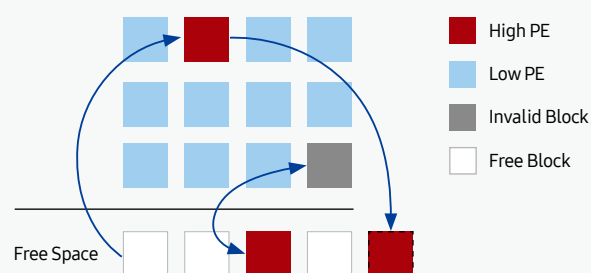


Background

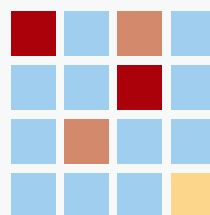
Unlike Hard Disk Drives (HDDs), Solid State Drives (SSDs) store electrons on NAND cells when writing data. With NAND flash, the stored data cannot be overwritten when new data is stored or erased. Since the writing and erasing operations (Program/Erase) of an SSD are carried out in different units, referred to as pages and blocks respectively, multiple cycles of Program and Erase are inevitable in writing and managing data. As more of such cycles are repeated, some electrons get trapped between cells and over time, these cells reach the end of their lifetime and encounter durability issues. Such a phenomenon is called the wear-out of cells and is responsible for the physical limits of the lifetime of NAND.

Therefore, proper management of NAND is crucial in extending the lifetime of the SSD. When data is repeatedly written in a certain area, the corresponding cells quickly wear out, so such repeated writing to the same cells should be prevented. Wear-leveling, a function that prevents repeated writing operations to a certain region, enables cells to be utilized evenly by swapping the blocks exposed to a high number of P/E cycles with free blocks, allowing the user to use the SSD longer under given conditions.

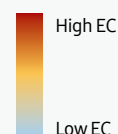
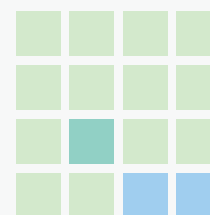
Figure1: WearLeveling



Without Wear-Leveling



With Wear-Leveling

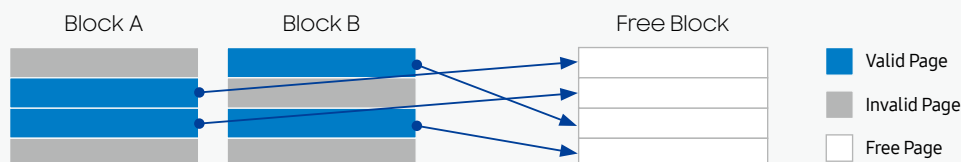


Since overwriting is impossible with NAND flash, existing data must first be erased in order to write new data to that cell, which slows down overall write performance of the SSD. Generally, it takes longer to erase data than to write it because, as mentioned previously, write operations are carried out in pages while erase operations are executed in blocks. To alleviate this decrease in write performance, a process called garbage collection (GC) is implemented to create free blocks within the SSD. This technology secures free blocks by collecting valid pages into a single location and erasing the blocks consisting of invalid pages. However, this too may sometimes result in slower performance in the unexpected case that garbage collection interferes with the host write. Therefore, free space in the SSD is required to allow the firmware (FW) feature to run smoothly. This process in which extra space is allocated is called over-provisioning (OP).

Figure 2: Garbage Collection

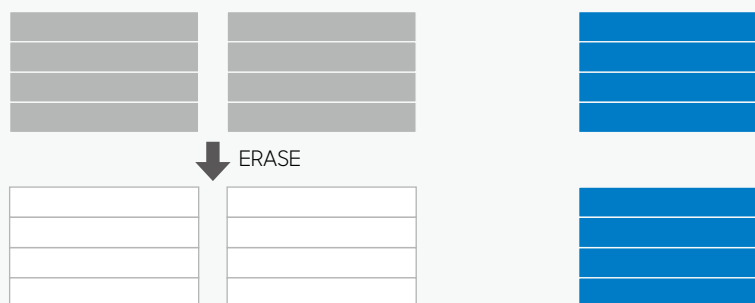
Step1

Collect valid pages



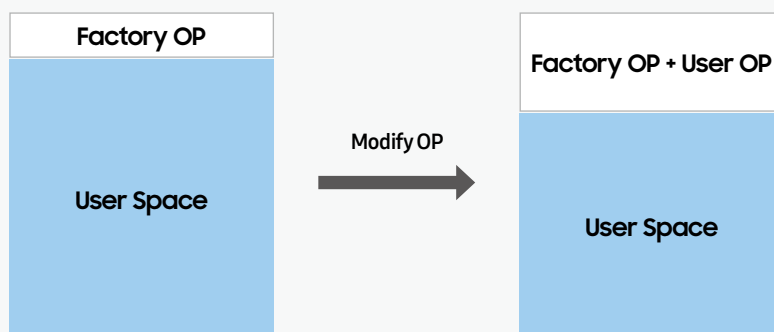
Step2

Erase Blocks consisting of invalid pages



What is OP (over-provisioning)?

As previously stated, over-provisioning refers to a function that secures extra space to allow for efficient use of the SSD by allocating a certain amount of the SSD's NAND flash to an over-provisioning space. This space can only be accessed by the SSD's controller and not by the host. Consisting of free blocks only, the OP region assists in efficient delivery of free blocks when wear-leveling or garbage collection is in progress and contributes to improved performance and lifetime of the SSD. Typically, Samsung DC SSDs are set to provide 6.7% of capacity for OP by default, but the user can manually adjust the size of the space if he or she requires additional OP depending on the user environment.



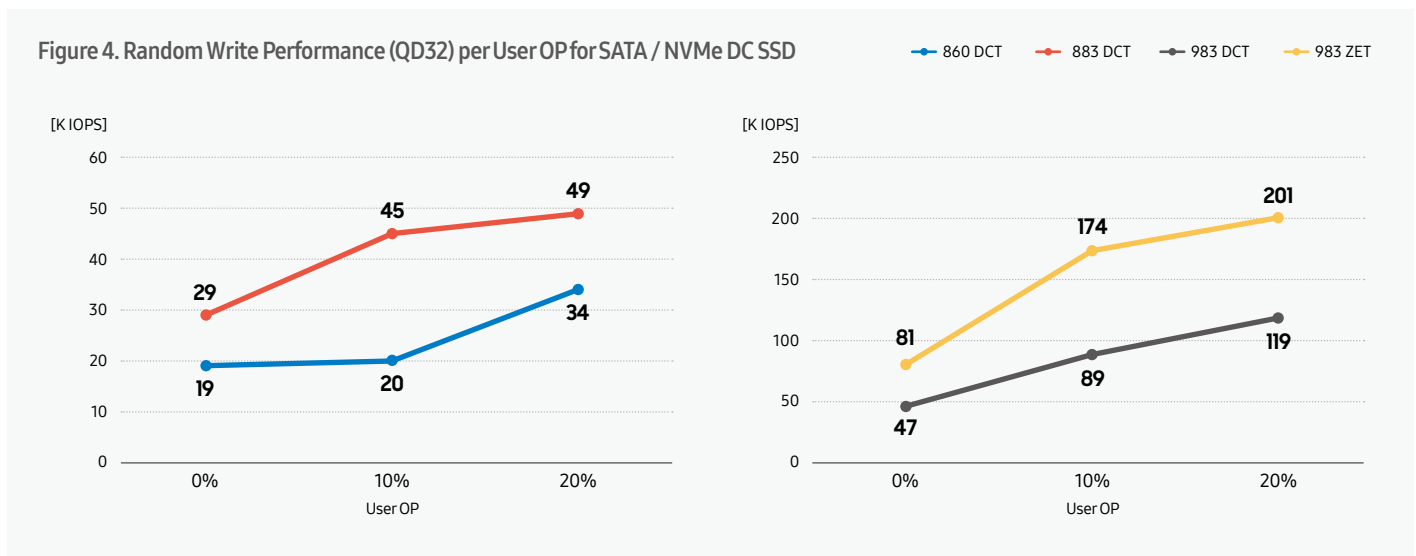
How do I calculate the OP ratio?

OP Ratio Formula: $OP (\%) = ((Physical\ Capacity - User\ Capacity) / User\ Capacity) * 100$

Ex) When 120 GB of a 128 GB SSD is used as the user capacity while 8 GB is assigned to the OP, the OP (%) is $((128 - 120) / 120) * 100 = 6.7 \%$.

What are the advantages of increasing OP?

Although there is no difference between the sequential and random write performance for fresh-out-of-the-box (FOB) NAND, the random write does not perform as well as the sequential write once data has been written over the entire space of the NAND. Random writes, smaller in size than sequential writes, mix valid and invalid pages within blocks, which causes frequent GC and results in decreased performance. If the OP is increased, more free space that is inaccessible by the host can be secured, and the resulting efficiency of GC contributes to improved performance. The sustained performance is improved in the same manner.



From the aspect of the lifetime of the product, internal operations such as GC cause the number of NAND writes to become greater than that of the host writes, and this also results in an increase in WAF (Write Amplification Factor), defined as the ratio of host writes to NAND writes. An increase in the WAF value indicates that unexpected NAND use is growing, and the lifetime of the product may be shortened before reaching the total byte written (TBW). A sufficient OP space decreases the NAND usage by improving the efficiency of internal NAND operations. It has the advantage of increasing the daily workload per day (DWPD) usable during the warranty period.

Example for Samsung DCT Series

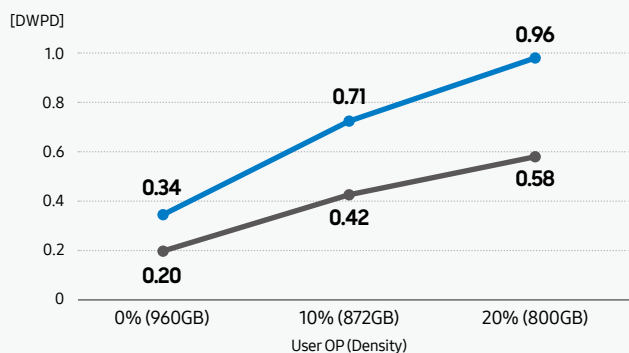
The graphs below show the estimated DWPD for each warranty by allotting additional user OP for Samsung's Data Center products (860/883/983 DCT, 983 ZET). The values in the graphs were calculated using the formula below and is a calculated value of each SSD, not a guaranteed value. The DWPD rises in accordance with the increase in the OP rate. Users can find the numbers needed for the calculations below through S.M.A.R.T. attributes, which are explained in more detail in the next section "Estimating life-time of an SSD using S.M.A.R.T. attributes."

$$\text{WAF} = \frac{\text{Physical Write Amount}}{\text{Host Write Amount}}$$

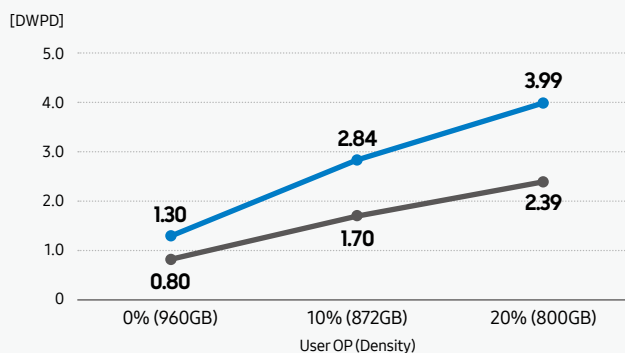
$$\text{DWPD} = \frac{\text{NAND PE Cycle} * \text{Raw Density}}{\text{Logical Density} * 365 * \text{Warranty Years} * \text{WAF}}$$

Figure 5. DWPD per User OP

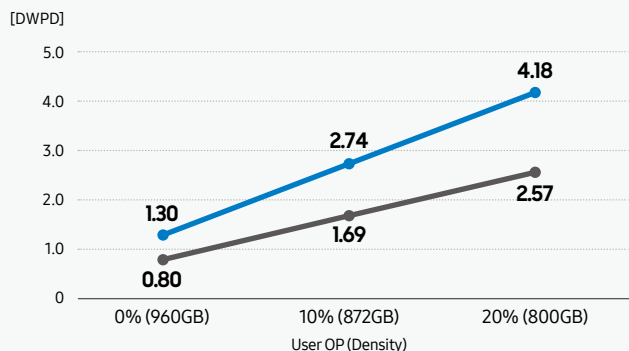
for 860 DCT 960GB



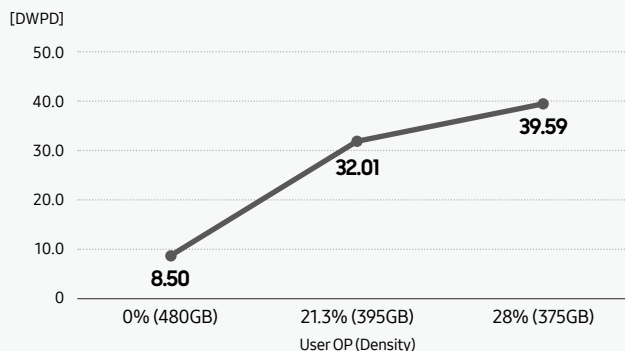
for 883 DCT 960GB



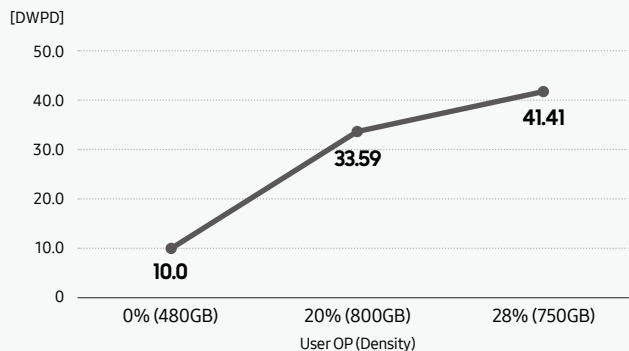
for 983 DCT 960GB



for 983 DCT 480GB



for 983 ZET 960GB



How do I estimate the lifetime of an SSD with S.M.A.R.T. attributes?

- Looking at the S.M.A.R.T. attributes table allow user to understand the wear of their SSD given a particular workload and time period. Alternatively, these attributes allow users to extrapolate the lifetime of their SSD. Please note that the below attributes are only available with SATA SSDs.
- ID 241 and ID 251 indicate the write amount of the host and NAND, respectively, and users can calculate the WAF of their SSD with these values.
- ID 177 indicates the number of wear-leveling operations and can also be interpreted as the overall average program/erase cycle. This value, along with the WAF value, allows the user to find out the DWPD.
- ID 247* represents the time in seconds that the SSD has been in operation since the workload timer was started. (Users can start/stop said timer at their discretion or let it run continuously. It is controlled through their SSD software tools).

* Please note that ID 247 is expressed in minutes for 860 DCT.

- ID 246 shows the share of I/O operations that were read commands since the workload timer (ID 247) was started and is expressed as a percentage. (Conversely, the share of write I/O operations can be determined by subtracting the given smart attribute reading from 100).
- ID 245 measures the wear of the SSD given the workload (ID 246) and the period of time over which these workloads have been sustained (ID 247). It is displayed as a per mille reading of the total wear of the SSD over its useful lifetime (i.e. a reading of 1000 would mean that the SSD has been worn out over the given time & usage pattern).

- Example applying to 883 DCT

A user has witnessed that the usage pattern of his SSD has recently decreased from 80% to 70% read I/O operations, and he would like to understand what impact this change has on the lifetime of his SSD. He has decided to run a test for 1 week. At the end of his test run, the S.M.A.R.T. attributes read as follows:

ID 245: 4, ID 246: 70, and ID 247: 604,800 (7 days x 24 hours x 60 minutes x 60 seconds)

To find the estimated end of life given the above readings, the user would need to work out the following calculations:

First, the user wants to understand how many more cycles could be run under the given test scenario before the SSD wears out completely. Therefore, the calculation yields: $1000 / 4 = 250$ cycles.

Second, the user then multiplies this number by the duration of the test run to find the total expected lifetime of the SSD in seconds. This calculation yields $250 \times 604,800 = 151,200,000$ seconds.

Finally, given the relatively abstract nature of large numbers expressed in seconds, the user then wants to express the calculated lifetime in years, months or weeks. If the user chooses to express the lifetime in years, he needs to make the following calculation: $151,200,000 / (365 \times 24 \times 60 \times 60) = 4.79$ years.

| ID | Attribute name | Status Flag | Threshold (%) |
|-----|--|-------------|---------------|
| 5 | Reallocated Sector Count | 110011 | 10 |
| 9 | Power-on Hours | 110010 | - |
| 12 | Power-on Count | 110010 | - |
| 177 | Wear Leveling Count | 010011 | 5 |
| 179 | Used Reserved Block Count (total) | 010011 | 10 |
| 180 | Unused Reserved Block Count (total) | 010011 | 10 |
| 181 | Program Fail Count (total) | 110010 | 10 |
| 182 | Erase Fail Count (total) | 110010 | 10 |
| 183 | Runtime Bad Count (total) | 010011 | 10 |
| 184 | End to End Error data path Error count | 110011 | 97 |
| 187 | Uncorrectable Error Count | 110010 | - |
| 190 | Airflow Temperature | 110010 | - |
| 194 | Temperature | 100010 | - |
| 195 | ECC Error Rate | 011010 | - |
| 197 | Pending Sector Count | 110010 | - |
| 199 | CRC Error Count | 111110 | - |
| 202 | SSD Mode Status | 110011 | 10 |
| 235 | POR Recovery Count | 010010 | - |
| 241 | Total LBAs Written | 110010 | - |
| 242 | Total LBAs Read | 110010 | - |
| 243 | SATA Downshift Control | 110010 | - |
| 244 | Thermal Throttle Status | 110010 | - |
| 245 | Timed Workload Media Wear | 110010 | - |
| 246 | Timed Workload Host Read / Write Ratio | 110010 | - |
| 247 | Timed Workload Timer | 110010 | - |
| 251 | NAND Writes | 110010 | - |

How do I adjust OP?

Users can use either the DC Toolkit or Linux HDParm Disk Management to adjust the available space for OP. This adjustment is limited to the space that is not in use only. If the user wishes to increase available space for OP, then he or she must clear up some space that is already in use.

How to adjust the OP setting with DC Toolkit

| Step | Description | CMD |
|------|--|-----------------------------------|
| 1 | Identify the device connected to the system. | DCToolkit.exe -L |
| 2 | Check the MAX ADDRESS setting available range. | DCToolkit.exe -d 1 -M -r |
| 3 | Set MAX ADDRESS value. | DCToolkit.exe -d 1 -M -s 12345678 |
| 4 | Confirm set value. | DCToolkit.exe -L |

```
Select Administrator: Command Prompt
C:\Users\hyo\Desktop\DCToolkit_V2.1.W.9.0>DCToolkit.exe -L
=====
Samsung DC Toolkit Version 2.1.W.9.0
Copyright (C) 2017 SAMSUNG Electronics Co. Ltd. All rights reserved.
=====
| Disk | Path | Model | Serial | Firmware | Optionrom | Capacity | Drive | Total Bytes | NVMe Driver |
| Number | | | Number | | Version | | Health | Written | |
=====
| *0 | | \\.\PHYSICALDRIVE0 | SAMSUNG SSD 863a | S361NX0H500008 | GXT51M3Q | N/A | 894 GB | GOOD | 0.98 TB | N/A |
| 1 | | \\.\PHYSICALDRIVE1 | SAMSUNG MZ7LH3T8HMLT-00003 | ABCDEFGHIJKLMNOP | HXT70F3Q | N/A | 447 GB | GOOD | 0.00 TB | N/A |
=====

C:\Users\hyo\Desktop\DCToolkit_V2.1.W.9.0>DCToolkit.exe -d 1 -M -r
=====
Samsung DC Toolkit Version 2.1.W.9.0
Copyright (C) 2017 SAMSUNG Electronics Co. Ltd. All rights reserved.
=====
Disk Number: 1 | Model Name: SAMSUNG MZ7LH3T8HMLT-00003 | Firmware Version: HXT70F3Q
Native SET MAX value of the disk is 937703087 LBAs.
=====

C:\Users\hyo\Desktop\DCToolkit_V2.1.W.9.0>DCToolkit.exe -d 1 -M -s 12345678
=====
Samsung DC Toolkit Version 2.1.W.9.0
Copyright (C) 2017 SAMSUNG Electronics Co. Ltd. All rights reserved.
=====
Disk Number: 1 | Model Name: SAMSUNG MZ7LH3T8HMLT-00003 | Firmware Version: HXT70F3Q
Disk Capacity updated to 5GB.
SET MAX Operation Completed. PowerCycle the disk.
=====

C:\Users\hyo\Desktop\DCToolkit_V2.1.W.9.0>DCToolkit.exe -L
=====
Samsung DC Toolkit Version 2.1.W.9.0
Copyright (C) 2017 SAMSUNG Electronics Co. Ltd. All rights reserved.
=====
| Disk | Path | Model | Serial | Firmware | Optionrom | Capacity | Drive | Total Bytes | NVMe Driver |
| Number | | | Number | | Version | | Health | Written | |
=====
| *0 | | \\.\PHYSICALDRIVE0 | SAMSUNG SSD 863a | S361NX0H500008 | GXT51M3Q | N/A | 894 GB | GOOD | 0.98 TB | N/A |
| 1 | | \\.\PHYSICALDRIVE1 | SAMSUNG MZ7LH3T8HMLT-00003 | ABCDEFGHIJKLMNOP | HXT70F3Q | N/A | 5 GB | GOOD | 0.00 TB | N/A |
=====
```

Conclusion

Although increasing the OP has the advantage of improving both the performance and lifetime of the user's SSD, it also decreases the available space to the host. This means that rather than excessively increasing it, an appropriate amount of space for the user's workload must be considered when adjusting the OP. Users can experience the most benefit from OP if the preferences are set up when the SSD is FOB. Therefore, it is recommended that the user's SSD product is FOB when the OP setting is set up.

For more information about the Samsung SSD, visit www.samsungssd.com.

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