Total Cost of Storage Ownership

A comparative review on SSD vs. HDD

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1 EXECUTIVE SUMMARY

When comparing solid state drives (SSDs) with hard disk drives (HDDs), many people stop after reviewing the initial acquisition cost of both storage media and conclude that SSDs are still too expensive to be seriously considered. However, when comparing storage alternatives, acquisition cost is just one of the many parameters that need to be considered. A better tool for comparison is the Total Cost of Storage Ownership (TCSO), where factors such as reliability, power consumption, performance, maintenance, downtime, disposal and many other factors need to be taken into account.

When reviewing the Total Cost of Storage Ownership, the distinct attributes of SSDs can make them a favorable solution over HDDs. Although the initial acquisition cost of SSDs is still higher than HDDs when comparing the price per gigabyte (GB), better reliability, lower power consumption, better I/O performance, and easier ways for disposal can lead to a reduction in the Total Cost of Storage Ownership for an enterprise.

This white paper will show that even a simple data center application that requires 100,000 random I/O operations per second (IOPS), an SSD-based solution can lead to hundreds of thousands of dollars of savings despite the 8x higher acquisition cost compared to a HDD.

With continuing price declines in flash technology, SSDs are becoming an increasingly viable option for many systems that have previously been price-prohibitive to look at this technology. IDC estimates that the SSD market will grow from $373M in 2006 to $5.4B in 2011, paving the way for many IT managers to optimize their systems with more robust, better performing and lower power solid state drives.

2 INTRODUCTION

Hard disk drives have continuously become smaller and less expensive, and their storage capacities have grown dramatically since their invention in the mid-1950s. The basic technology has remained the same: rapidly spinning platters coated with ferromagnetic material hold the data, while an arm equipped with read/write heads hovers just above them. Despite the fact that this technology reached a very high level of maturity in recent years, it still suffers from a number of basic limitations due mainly to its mechanical nature. Hard drives are vulnerable to shock, vibration, and temperature fluctuations; consume relatively high amounts of power in order for the platters to spin; produce a relatively large amount of heat, and take time to start.

In many systems, HDDs are the main contributor to failures. Recent industry studies[3,4] show annual failure rate numbers of 4%-8.6% (see section 5.2) in controlled data center environments. It is only logical to assume that double-digit failure rates will be seen when HDDs are embedded in rugged systems that are deployed in environments with shock, vibration, temperature extremes, and humidity. Expenditures for replacement can substantially increase the overall cost and should be thoroughly reviewed when calculating the Total Cost of Storage Ownership.

Even though the initial cost of SSDs is typically more than a HDD, it is important to understand the Total Cost of Storage Ownership. Where in the past the operating expense (OPEX) — power, cooling, maintenance, replacement — was insignificant versus the capital expense (CAPEX), the roles have reversed. According to Gartner's Michael Bell[1], in 2009 the IT industry will spend twice as much for power and cooling than they did to buy the hardware. Therefore, to fully determine the Total Cost of Storage Ownership, factors such as life expectancy, annual failure rates, system downtime, power consumption, maintenance, and replacement costs are key contributors to the TCSO formula. In such a calculation, the higher reliability, lower power consumption and better random IOPS performance of solid state drives will reveal their full advantage, resulting in a lower overall TCSO.

This white paper will review the Total Cost of Storage Ownership for systems that use traditional HDDs versus those that use SSDs.

Figure 1: HDD vs. SSD

[1] March 15, 2007, Hot Storage - - Power and cooling concerns, SearchStorage.com

3 DEFINING TOTAL COST OF STORAGE OWNERSHIP

The Total Cost of Storage Ownership calculation is designed to assess both direct and indirect costs for owning a storage product or system over its life cycle. TCSO is used in IT, Telecom, Military and other mission critical systems to arrive at a final figure that will reflect the effective cost of purchase, all things considered. The final numbers can then be used to compare alternatives for the same length of time.

TCSO identifies costs as being made up of two major components - direct and indirect. Direct costs traditionally form the area that organizations find easiest to measure. Typically, direct costs are made up of labor and capital costs. Indirect costs are more difficult to measure and rationalize. A Gartner survey[2] shows that despite the difficulty of measuring them, indirect costs can typically represent a substantial component - as much as 60% - of the total cost of managing and owning an IT infrastructure. According to various industry studies, costs incurred after the initial deployment can comprise up to 80% of IT cost, and it costs more to operate a storage device over three years than to buy it.

When performing a TCSO study, the following cost types should be considered:

- Acquisition/procurement
- Installation
- Environmental (space, power, cooling)
- Maintenance/operation
- Management/training & administrative
- Repair/Upgrade
- Disposal
- Downtime: direct and indirect (including reputation loss)
- Replacement/re-qualification

Storage is one of the main components in any mission-critical system and requires thorough scrutiny. High failure rates, power consumption, maintenance/repair, and performance are all cost factors that should be reviewed when choosing the appropriate storage technology. TCSO, once appropriately measured, analyzed and managed, is a critical means of controlling storage expenditure and measuring the effectiveness of storage implementation.

[2] Gartner Group, Total Cost of Storage Ownership – A User-oriented Approach, February 2000

4 ACQUISITION COST – HDD VS. SSD

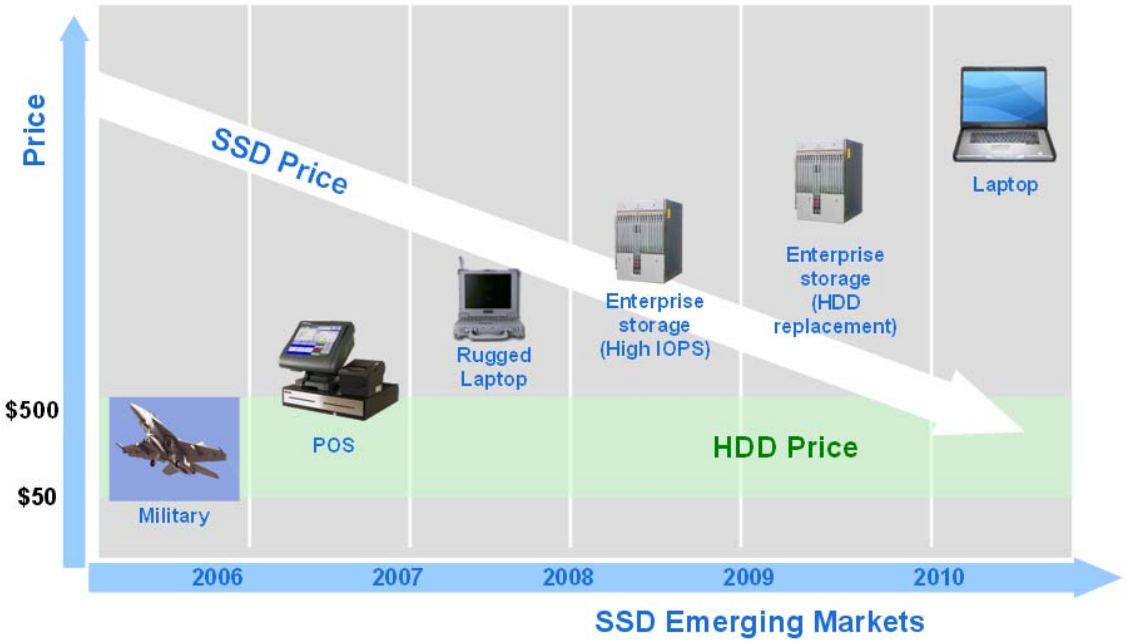
When comparing the acquisition cost of a HDD vs. SSD, the balance will most likely fall in favor of the mechanical HDD. Over the past decade, the base cost for a hard disk drive has not changed substantially. Depending on whether the drive is targeted for the consumer desktop market or high-performance enterprise market, HDD prices have been stable, ranging from $50 for the cheapest models to $500 for high-end enterprise models. Technology advances have allowed more Gigabytes to be installed in the same or smaller space, but the base cost has stayed fairly constant throughout this period.

The same cannot be said about solid state drives. With the flash manufacturers pushing product roadmaps to increase density and reduce costs, flash density within the same silicon footprint has been doubling nearly every 12 months for the past decade. For example, Samsung has been able to introduce 6 new process geometries in the past 8 years, moving from 220nm in 1999 to 60nm in 2006. This has resulted in a doubling of capacity every year for the same casing size, sharply reducing flash cost per byte.

Ten years ago, a storage budget of $250 could buy an IT manager a 1.2GB enterprise-class HDD, but only 5MB of solid state storage. Five years ago that same budget would buy an 18GB HDD and a 200MB SSD, and today it would buy a 75GB SAS/SCSI enterprise-class HDD and a 15GB solid state drive. Where the HDDs capacity showed an increase of 60% in capacity, solid state disks capacity grew by an impressive 3000% for the same budget.

In the past, the main barrier to the deployment of flash disks has been their high cost per byte of storage. The cost barrier is diminishing rapidly, with flash prices showing a 20-30% yearly decline over the past decade. It is inevitable that more and more applications will be able to incorporate solid state disks as their main storage component. Figure 2 shows the price trend of solid state disks vs. HDDs, and illustrates some of the new markets that solid state storage can address due to its continuous price decline.

Figure 2: Price and application trends in storage technology



As flash densities continue to double every 12-18 months in the same silicon footprint, solid state disks become more cost-effective, making them ideal replacements for mechanical HDDs in many mission and business-critical applications.

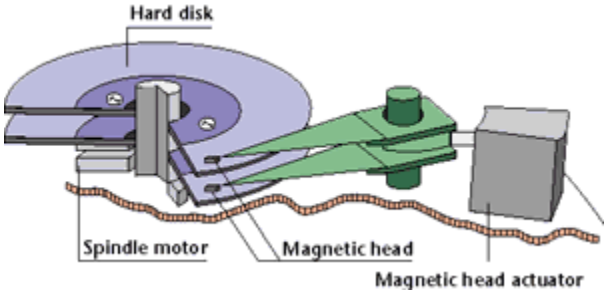
5 SYSTEM DOWNTIME

Hard disk drives are the number one component being replaced in storage systems worldwide, causing an overall increase in Total Cost of Storage Ownership. The overall failure rate in controlled environments show reasonable - if not desirable – numbers, ranging from 2 to 8.6%, based on existing studies[3,4] and industry data. However, when deployed in systems that are operating in conditions of high shock, vibration, high altitude, humidity, extreme temperature ranges and high duty cycles, the hard-drive failure rate can quite easily increase to double-digit figures, which is completely unacceptable for mission and business-critical systems.

5.1 Causes for HDD failure

The biggest problem with hard disk drives is their low reliability due to the fact they have moving parts. Figure 3 below shows the mechanical nature of hard disk drives. There are several causes for failure, but the majority can be related to mechanical problems and environmental factors. The most common mechanical failure is a head crash, which can be caused by multiple reasons, including physical shock, movement of the system, static electricity, power surges, contamination of the platters and mechanical read-write head failure.

Figure 3: Mechanical nature of hard disk drive



5.2 Two important studies

In February 2007, two extensive studies on hard disk drive failures were presented at the USENIX conference on File and Storage Technologies (FAST 2007). Both studies were conducted independently and observed disk drive populations of more than 100,000 drives in a controlled environment:

- The first study, conducted by Google[3], examined a population of more than 100,000 hard drives under deployment within Google's computing infrastructure. The population contained several models from the largest HDD manufacturers and were deployed in professionally managed datacenter facilities. During the 9 month study, Google found annual failure rates of 6% to 8.6% on hard drives that were used for two or more years (some of the drives were already deployed before the start of the study). One of the key takeaways from the study was that the Self-Monitoring, Analysis and Reporting Technology (SMART) model associated with the drives was unable to create a meaningful predictive failure model that could warn engineers of impending drive failure.
- A second study, conducted by Carnegie Mellon University[4] examined over 100,000 enterprise-class and desktop-class hard drives in large production systems, including high-performance computing sites and Internet services sites. The data sheets for those drives listed MTBF between 1 million to 1.5 million hours, which the study said should mean annual failure rates "of at most 0.88%." However, the study showed typical annual replacement rates of between 2% and 4%, and up to 13% observed on some systems.

[3] Failure Trends in a Large Disk Drive Population, Google Inc., 2007
[4] Disk Failures in the Real World: What Does an MTTF of 1,000,000 Hours Mean to You? Carnegie Mellon University, 2007

Both the Google and Carnegie Mellon studies were conducted in controlled environments inside optimized data centers. It is expected that annual failure rates of hard drives in environments that are more susceptible to power fluctuations, temperature changes, shock and vibration and other environmental conditions can very quickly reach double-digit figures. This would make mechanical HDDs by far the weakest link in mission-critical systems and the number one source for system downtime.

5.3 The cost of HDD failure

An annual failure rate of 4-8% indicates that as many as one out of every 12 hard disk drives deployed is up for failure! In a controlled environment, with full-time IT-staff available to replace disks without system downtime, this may still be manageable. However, when the hard disk is part of a field-deployed system, service costs can increase the bill and overall TCSO substantially. Sending out a service engineer is typically costly, ranging from a few hundred to a few thousand dollars in replacement, labor and travel costs. In addition, overall system downtime can drive the bill even higher, where additional factors such as company reputation and customer satisfaction need to be taken into consideration.

Example:

This example is based upon information and feedback from an Adtron customer that delivers systems to the medical market. The company has systems deployed in the field that use a total of 15,000 storage devices (HDDs). The company estimated that the annual failure rate (AFR) of the HDDs in their systems was ranging from 5% in the first year, leading up to 9% in the 5th year. In comparison, the system could be deployed with SSDs with an AFR of 0.1% in the first year, leading up to 0.5% in the 5th year. Please note that these AFR numbers are assumptions, based on Adtron's statistics within its customer base.

The calculation also takes into consideration the following assumptions:

- The customer requires a highly reliable HDD drive, and HDD acquisition cost will be $250. The price stays stable for the full 5 years.
- The SSD acquisition cost will be $500 at the time of deployment, and will show a price reduction of 20% per year (in line with historical SSD market price trends).
- Initial acquisition cost for the system with HDDs is 15,000 x $250 = $3.75M
- Initial acquisition cost for the system with SSDs is 15,000 x $500 = $7.5M
- The cost for replacing a drive is $750 to send out a technician, plus the cost of the drive.

Based on the above assumptions, the replacement cost for both systems are shown in Table 1 below.

Table 1: Replacement cost SSD vs. HDD in Field Deployed System

	HDD Failure Rate	HDDs Replaced	HDD cost	Total Replacement Cost	SSD Failure Rate	SSDs Replaced	SSD Cost	Total Replacement Cost
Year 1	5%	750	$250	$750,000	0.1%	15	$500	$18,750
Year 2	6%	900	$250	$900,000	0.2%	30	$400	$34,500
Year 3	7%	1050	$250	$1,050,000	0.3%	45	$320	$48,150
Year 4	8%	1200	$250	$1,200,000	0.4%	60	$256	$60,360
Year 5	9%	1350	$250	$1,350,000	0.5%	75	$205	$71,610
Total		5250	$250	**$5,250,000**				**$233,370**

Table 2 shows the total Cost of Storage Ownership for these two storage technologies, when the acquisition cost is added into the calculation. As can be seen from Table 2, a total cost savings of **$1,266,630** can be achieved for SSD-based systems over a period of 5 years, even though the initial acquisition cost is twice as high.

Table 2: Total Cost of Storage Ownership SSD vs. HDD-based systems

	HDD	SSD	Cost comparison SSD vs. HDD
Acquisition cost	$3,750,000	$7,500,000	($3,750,000)
Replacement cost (5 years)	$5,250,000	$233,370	$5,016,630
Total	$9,000,000	$7,733,370	**$1,266,630**

Table 3 below shows the cost savings over a period of 5 years for the same systems, but using 500 up to 10,000 drives deployed. The same calculation method is used as in the above example.

Table 3: Cost Savings in systems with 500 up to 10,000 drives

Drive Quantity	Cost Savings
500	$42,221
1,000	$84,442
5,000	$422,210
10,000	$844,420

6 POWER CONSUMPTION COST

Through 2009, energy costs will emerge as the second-highest operating cost in 70% of worldwide data center facilities, according to a recent Gartner report[1]. Today, servers account for 40% of the data center's overall power consumption, with storage consuming 37% of the overall power. Analysts expect that U.S. companies will spend twice as much on power and cooling by 2009 as they did to acquire their IT devices and within the next several years, energy costs will consume up to one-third of IT budgets. IDC recently stated that IT organizations currently are spending a quarter of every hardware dollar on power.

Because solid state drives have no rotating media, read/write heads, and spinning motors, it is easy to understand why SSD power consumption numbers are substantially lower than those for mechanical hard disk drives. Table 4 shows a comparison between Adtron's FlashPak 2.5" SATA SSD and two HDD models from leading HDD manufacturers.

Table 4: Power Consumption - SSD vs. HDD

Power Consumption	FlashPak 2.5" SATA	HDD(Note 1) (7,200 RPM)	HDD(Note 2) (10,000-15,000 RPM)
Idle	2.0 – 3.2W	8.0 – 9.0W	8.0 – 14.0W
Operating	2.1 – 5.3W	8.0 – 12.0W	13.0 – 19.0W

Note 1: Parameters based on HDDs: Seagate Barracuda ES.2 and WD RE2 drives
Note 2: Parameters based on HDDs: Seagate Cheetah 15K.4 and WD Raptor

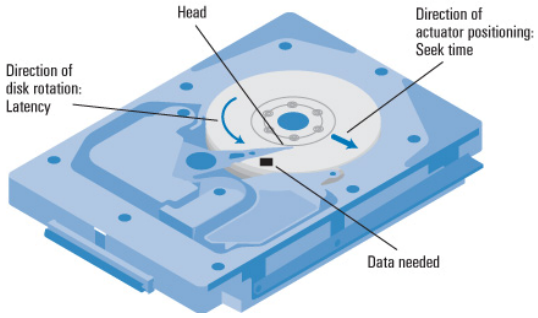
Gartner projects that the power consumed on a per rack basis will exceed 6KW in more than 50% of all data centers within two years. That number is expected to rise to 70% to 80% within four years due to the increased density of IT equipment, and that the ratio of power to cooling will hit 1:1[1]. Therefore, not only should the cost of power be assessed, but also the cost of cooling the equipment.

While the power consumption difference will not be of any great influence in the overall TCSO in a field-deployed system that contains one or two storage units, it can lead to increased cost savings when looking at blade servers, data centers and other enterprise storage systems where dozens or hundreds of units are implemented and power and cooling cost are a substantial factor of the overall OPEX.

7 HIGHER IOPS CAN RESULT IN COST SAVINGS

A hard disk's performance is characterized by its access time; which is the sum of the seek time required to move the head to the correct track, the rotational latency for the disk to rotate until the head is over the desired sector, and the transmission time needed to transfer data to or from the sector. Figure 4 shows the movement parameters involved in transferring data to/from HDDs.

Figure 4 Latency and Seek time in mechanical HDD



The negative impact of the HDD's mechanical operation is greatest when many small files are read in a random manner. In performance-sensitive applications, access time is a much more significant factor than data transfer time. In data center applications that must perform high, random read/write transactions, hundreds of HDDs must be deployed to offset the low IOPS performance inherent to each disk drive.

Since solid state storage does not have any moving parts, latency and seek time are almost non-existent. This contributes to an IOPS performance for solid state disks that is far superior to hard disk drives. Where enterprise-class HDDs show throughput numbers ranging from 200 to 500 IOPS, most solid state disks are a factor of 10x higher, ranging from 2,500 for entry-level SSDs to 50,000 IOPS for high end enterprise-class SSDs. Table 5 shows typical performance and power parameters for solid state drives vs. enterprise-class HDD.

Table 5: Performance Comparison - SSD vs. HDD

Performance	Solid State Drive	enterprise-class HDD
Access Time	< 0.3ms Read/Write	5.8ms Read 6.3ms Write
IOPS	3,500 – 20,000	319-512
Power Consumption (operational)	2-5W	17.5-19.5W

Note: Parameters based on Seagate Cheetah 15K.4 (ST3146754xx), tested by www.StorageReview.com under various workloads.

So, how does higher random read/write performance result in reduced Total Cost of Storage Ownership? If one solid state drive with 5,000 IOPS can replace 10 HDDs specified at 500 IOPS, significant cost savings can be achieved. In large database applications, where thousands of hard disk drives are deployed, cost can also be saved in power consumption, cooling, rack cabinets, floor space, and maintenance.

Example:

This example shows a database application that has a performance requirement of 100,000 random IOPS. This can be achieved by installing either 222 enterprise-class HDDs (450 IOPS, 18W operational), or 20 Solid State Disks (5,000 IOPS, 4W operational). Service cost is assumed to be $250, as this is in a controlled datacenter with permanent IT staff on-site.

Table 6 below shows a cost comparison for the database application if it were deployed with solid state storage vs. traditional hard disk drives. Please note that a higher acquisition cost for the SSD was used in this example on purpose. It is meant to emphasize the fact that even at a factor of 8x higher initial cost, an overall cost savings of **$96,991** over a 5 year period can be achieved.

Table 6: Cost Comparison - SSD vs. HDD

Cost	Solid State Drive	enterprise-class HDD	Comments
Acquisition Cost			
Drives needed	20 SSD @ $2,000/drive	222 HDD @ $250/drive	
Chassis	1 x $1,000	13x $2,000	3U Rack can contain 18 HDDs /w 450W power supply. Cost 3U= $2,000/ea Cost 1U = $1,000/ea
Rack Cabinet	$0	$1,000	44U Rack Cabinet = $1,000
Total	$41,000	$82,555	
Operational Cost			
Power (24/7 operation, 5 years)	20 SSD x 4W x 24 hrs x 365 days x 5 years x $0.10 = $350	200 HDD x 18W x 24 hrs x 365 days x 5 years x $0.10= $17,502	10¢ per kWh[5]
Cooling	$350	$17,502	Cost of cooling is the same as cost of power consumption
Total	$700	$35,004	
Other Cost			
Replacement/Maintenance (5 years)	0.5% failure rate @ $2000 SSD replacement & $250 service cost Total: $1,125	4% failure rate @ $250 HDD replacement & $250 service cost Total $22,222	Cost of system downtime not included
Total	$1,125	$22,222	
Total Cost	**$42,825**	**$139,817**	

Note: Based on chassis and cabinet dimensions by Rackable Systems.
Note: Another factor that should be taken into consideration is floor space, depending on the geographical region.

[5] Estimate used based on http://www.think-energy.net/electricitycosts.htm The U.S. average in 2006 is 8.83¢ per kwH.

8 COST OF DISPOSAL

IT managers must also begin to factor in costs for disposing end-of-life equipment, making disposal part of the TCSO analysis. In certain applications, removing all data from the drive is required prior to disposal. Various military standards (NISPOM DoD 5220.22-M, NSA 130-2, Air Force AFSSI-5020, Army AR380-19, Navy NAVSO P-5239-26, IRIG 106) define how a drive should be cleared and/or sanitized, with a combination of erasing and writing different patterns to the drive. Because of the magnetic component of a HDD, clearing data from the drive is not a trivial matter. Bulky degaussers are required for the task (see Figure 5).

Figure 5: Degausser for erasing data from HDD media

Solid state disks, based on NAND flash technology, are easy to clear/sanitize through the use of either a software command or a remote push button. No degausser is required for the task.

When establishing a TCSO, remember to include the cost of safe disposal, and the cost of ensuring that sensitive data is effectively removed from the drive.

9 TCSO CALCULATION MATRIX

Table 7 is an aid to calculate the Total Cost of Storage Ownership for systems deployed with SSD vs. HDD.

Table 7: Total Cost of Storage Ownership Matrix

Parameter	SSD	HDD	Comments
TCSO Period (years)			Numbers of years to calculate the TCSO
Yearly interest rate (%)			Used to discount costs incurred over time to PV (today's time) assume costs are incurred at the end of each year.
Annual Failure Rate			Annual Failure Rate can vary for HDD, depending on operational conditions
Warranty			HDDs have limited warranty only
Initial cost			
Disk acquisition cost			Depends on model & capacity, and requirement for additional H/W, such as server racks, cabinets, etc.
Mounting equipment acquisition cost			If additional H/W is needed, such as server racks, cabinets, etc.
Installation cost			
Operational cost			
Training Personnel			
Power consumption			Power consumption of HDD 3x higher than SSD
Cooling			When system is deployed outside of the 5-55C operating range of HDD, cooling cost must be added to TCSO.
Replacement cost			Depends on annual failure rate & service costs
Disposal cost			When used in military application, data may need to be erased. Degaussers are required for HDD
Floor space			Required for data centers
Downtime cost			
Replacement cost			Related to annual failure rate
Service cost			Cost of field service technician
System downtime			Costs associated to losing manufacturing/production/billing time
Reputation loss			If measurable
Total Cost of Storage Ownership			

10 SUMMARY

While the initial acquisition cost for storage favors mechanical HDDs, many other factors must be considered when choosing a storage technology for implementation

Factors such as power consumption, IOPS performance, maintenance and replacement, disposal, and failure rates are all part of the equation when assessing the Total Cost of Storage Ownership. With rising energy and consumption costs, power, cooling, space and disposal should become integral parts of the TCSO analysis for every storage device an organization buys.

Solid state drives can alleviate many of the existing problems that HDDs bring with them. Improvements in reliability, IOPS performance, power consumption and data sanitization are clear and direct benefits. With continuing price decline of 20-30% per year, solid state drives are becoming more and more compelling for deployment in any system that suffers from HDD related issues.

About the Author

Esther Spanjer is Director of Technical Marketing at Adtron Corporation. With more than 10 years of experience with flash-based solutions, Ms. Spanjer has gained valuable insight into the use of this rapidly evolving technology in a wide range of embedded applications in the military, aerospace, communications and industrial markets. She joined Adtron to help evangelize the use of flash technology for new types of applications in both the traditional markets and the emerging enterprise market. As users become more familiar with the full range of benefits of flash technology, she believes that flash-based storage will be adopted in a broader range of what have typically been thought of as hard-disk applications.

Ms. Spanjer received a B.Sc. degree in Electronic Engineering from the Technical University Amsterdam (Netherlands) in 1991. She can be reached at espanjer@adtron.com.

About Adtron

Founded in 1985, Adtron is the leading designer and global supplier of high performance and high capacity solid state flash disk drives. Adtron Flashpak SSDs integrate seamlessly into defense/ aerospace, industrial automation, medical, transportation, telecom and enterprise applications. Based on Adtron's advanced ArrayPro™ performance engine, Adtron solid state flash disk drives deliver superior sustained read and write rates and are designed to reliably meet stringent environmental requirements. The Adtron Quality Management System is ISO 9001:2000 certified. Adtron is headquartered in Phoenix, Arizona with channels in all global markets.

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