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Choosing the Appropriate Storage Media to Collect Video-based Evidentiary Data

For Mobile Law Enforcement



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1. Introduction

Video surveillance represents a technology that has been well established for decades in fixed-site, security-based applications. Recently, this technology relied primarily upon either live monitoring or analog recording regimes (VHS tapes) for record keeping and storage. Vehicle-based applications were exclusively limited to bulky, video recording equipment and the inherent limitations and weaknesses associated with tape-based recording technologies. The rapidly evolving advancements in computer processing speeds, video compression algorithms (video codecs), and storage media has created an explosion in the utilization of video for mobile applications, i.e., mass transit, emergency response, law enforcement vehicles. The worth of this technology has been enhanced additionally with the ability to simultaneously collect metadata with the video/audio data. Thus, the value of video-based data collection is today playing a larger and larger role in daily law enforcement activities.

Video-collected evidentiary data represents perhaps one of the most powerful tools for accountability and ascertaining liability/innocence in those scenarios requiring litigation or incident corroboration. However, as a form of electronically stored information (ESI), any recorded video/audio/metadata is subject to the guidelines specified in the Federal Rule of Evidence which means that data integrity is of paramount importance from the point of initial collection to archival storage¹. Potentially, the weakest or most vulnerable link in the evidentiary data chain is the choice of electronic storage media. This is uniquely relevant to mobile applications where the rigor of environmental conditions may place exceptional stresses upon the storage media resulting in data corruption or loss. Careful selection of the appropriate storage media can maximize the likelihood of data integrity.

This white paper compares the various advantages and limitations between current electronic storage media, examines industry trends, and predicts the future of removable storage media. In today's market there are three primary options available for collecting and/or storing electronic data;

- 1) Magnetic media: hard drives – digital video recorders (DVR's)
- 2) Optical media: CD's, DVD's, etc.
- 3) Solid-state media: compact flash (CF), secure digital (SD), USB drives, etc.

This assessment will ultimately provide guidance to those agencies and individuals involved in the purchase, upgrade or selection of mobile-based video systems to make informed choices about their selection of removable storage media as it pertains to their mobile-based video system.

2. Factors to Consider in the Selection of Removable Storage Media

The electronic memory storage business reflects an extremely fluid and dynamic industry that is constantly evolving in response to consumer demands and rapid technological innovations. Consequently, some facets of this industry are currently experiencing nearly exponential growth in storage capabilities, speeds, etc., making it increasingly challenging to predict where the market will be even in a few years. Despite these uncertainties, the following criteria are applicable as standards for selecting an appropriate removable storage media:

- Capacity
- Cost
- Longevity
- Durability
- Obsolescence

These criteria are elaborated upon in the ensuing paragraphs. The relative prioritization or importance of each of these points depends upon the particular application and fundamental goals desired by the user.

2.1 Capacity

The electronic media storage option provides a storage capacity appropriate for the quantity of data under normal operating procedures. This may also be dependent upon whether the media represents a temporary depository (prior to transfer to some archival site) or signifies the final archival storage medium. Minimizing the number of actual media to be managed will generally be more efficient and cost effective.

2.2 Cost

At least two elements must be considered when assessing the relative costs of electronic storage media – the cost of the media itself and the total cost of ownership. Valid comparisons of media costs are generally made on a price per Gigabyte (Gb) basis. The total cost of ownership includes costs for purchasing and maintaining the necessary hardware/software, and any storage equipment required. Support costs and the manufacturer’s quoted “mean lifetime before failure” of the relevant media must also be taken into account.

2.3 Longevity

The media storage option chosen should have a proven life span appropriate to its usage or application, i.e., is this for archival purposes or daily activities? Generally this may span years to perhaps decades. Great longevity is, however, not necessarily

an advantage: over longer timescales, obsolescence of the drive technology used to read the medium will typically be a much more significant factor than physical deterioration of the storage medium itself. The durability of the media could have a profound impact on this criterion as well.

2.4 Durability

The electronic storage media should have low susceptibility to physical damage and be tolerant of a wide range of environmental conditions without data loss. Any reasonable measures required to counter known susceptibilities (such as packaging or storage, for example) should be affordable and readily achievable.

2.5 Obsolescence

The electronic media and its supporting hardware should preferably be based on mature technology. The technology should be well established in the market place and widely available. Media technologies that are based upon open standards for both media and drives would be generally preferable to those that are proprietary to a single manufacturer. The drive/media technologies should have projected lifetimes at least equal to or longer than the anticipated data storage or archival duration.

3. Memory Storage Media

Memory storage media fall into three broad categories based on the nature of the storage medium and the method of data recording. The following is a brief primer on; 1) Magnetic media, 2) Optical media, and 3) Solid-state media.

3.1 Magnetic Media

The oldest, most widespread, and established electronic storage medium is

Table I. Magnetic Media	
Platter diameter	Primary Market
3.5-inch	Desktops; Servers
2.5-inch	Mobile; Servers
1.8-inch	Consumer electronics

represented by the hard disk drive (HDD) which stores digitally encoded data on rapidly rotating (3,600-15,000 rpm) platters that are coated with a ferromagnetic film. Data is recorded (or removed) by changing the magnetic properties of the film which is accomplished through a read-write head mechanism that operates in close proximity to the surface of the platter as it rapidly rotates. The current HDD market is primarily represented by several different platter sizes (Table I.), as well as other less common dimensions (1.3-inch, 0.85-

inch) that are used in specialized applications or being phased out of widespread production. These sizes have evolved over the years to address and improve various performance, power, and cost issues driven by market demands. It has been estimated that in 2002, nearly 90% of all electronic data was stored through this format.²

3.2 Optical Media

The optical memory storage medium consists of a diverse family that is most commonly represented by; the compact disc (CD), digital video disc (DVD), and newest, Blue-ray disc (BD), each with numerous extensions (+R, -R, R/W, etc.). This technology utilizes electromagnetic radiation (different wavelengths of laser light) to read and/or write digitally encoded data onto a variably rotating (200-10,000 rpm), thin plastic disk which contains a light-sensitive and/or light-reflective substrate. Data is stored as “pits and lands” (valleys and bumps) in the substrate that reflected laser light may interpret as data. Writing data to the medium requires the laser to “etch” pits into the light-sensitive or reflective substrate. Presently, the CD and DVD represent the most common storage medium for consumer audio and video distributions. Due to the memory intensive nature of video and the limited capacity of the CD, it will not be discussed in the following sections.

3.3 Solid-state Media

Solid-state memory or “flash” memory represents the most recent innovation in memory storage media. It is termed “solid-state” in that it contains no moving parts unlike the electromechanical systems that characterize magnetic and optically-based storage media. This form of memory media stores data in a large array of tiny transistors, whereby each transistor acts as a memory cell that can store one (or up to four) bit(s) of data depending upon the wiring architecture utilized between transistors. Fundamentally, flash memory can be thought of as a silicon version of a small hard disk drive and its inherently small form factor has seen an explosion in consumer applications. This has led to a form of “memory wars” in the solid-state memory industry where there are currently several manufacturers producing different card standards and formats (Figure 1.) in an attempt to attain dominance in the market. This paper will focus specifically on the characteristics of compact flash memory storage. Between the various designs currently available it is the oldest and most established of the solid-state media formats and has a number of features (robustness, storage capacity, etc.) that make it best suited for the types of stresses and conditions that may occur in a mobile environment.

A relatively new innovation of the solid-state media industry has been the development of solid-state drives (SSD). These represent an array of flash memory components that are packaged in a form factor to mimic a hard drive. This permits

capacities like that of a hard drive yet in a solid-state form, with all the advantageous features found in solid-state media, i.e., no drive latency, high access rates, durability, low power consumption, etc. Although this facet of the solid-state industry is still in its infancy, some predict this will ultimately represent the predominant memory storage format of the future.

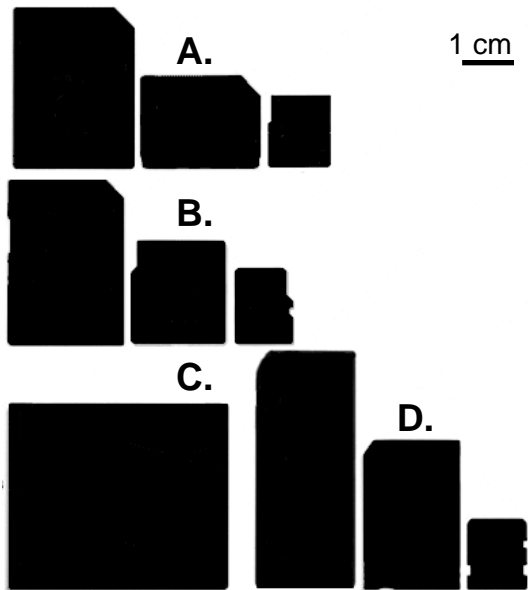


Figure 1. Relative form factor comparison of the most common solid-state media in the market today. The media vary in thickness from less than 1mm up to 5mm. A. Multimedia Card (MMC); MMC-mini; MMC-micro. B. Secure Digital (SD); SD-mini; SD-micro. C. Compact Flash. D. Memory Stick Pro; Memory Stick Duo; Memory Stick Micro.

4. Comparisons

4.1 Storage Capacity

Video recording can generate a tremendous amount of raw data depending upon

Table II. STORAGE CAPACITY

Media Type	Memory Capacity (in Gb)
Magnetic (HHD)	up to 1500
Optical: DVD (single layer)	4.7
DVD (dual layer)	8.5
Blue-ray	25
Blue-ray (dual layer)	50
Solid-state: Compact flash	up to 100

Based on commercially available media as of Oct., 2008.

the resolution, frame-rate, and duration. Uncompressed video takes nearly one megabyte per still frame. Playing or recording video at thirty frames per second means that every second of typical video will require roughly 27 megabytes to store. This number would be slightly larger if one includes audio and other miscellaneous metadata. Conservatively, this is equivalent to roughly 100 Gigabytes per hour for continuous recording and obviously even a large hard drive would fill up in short order! Fortunately, the key to this dilemma has been the development of video compression algorithms (video codecs) that significantly reduce the file size permitting manageable video/audio

transmission and/or storage options. Currently, the MPEG-2 or MPEG-4 video compression standards are most widely in use. These codecs would take the previous example of 100 gigabytes per hour and reduce this to roughly 1 to 4 gigabytes per hour depending upon the compression scheme used.

Clearly, if large storage capacity is of primary concern, magnetic media far outweighs all other storage media. Hard drive manufacturers such as Seagate and Hitachi are anticipating 2 terabyte capabilities on the market by 2009 and multi-terabyte (10-50) capacities within the first half of the next decade³.

The optical media industry plans on coming online with quad layer blue-ray discs within the next two years doubling its potential capacity to 100 gigabytes.

Presently, the solid-state memory industry is undergoing an explosion in demand and growth with increases in storage capacity changing so rapidly that nearly every six months is seeing the availability of larger capacities as smaller capacities are becoming obsolete. SSD's are following this same trend in capacity with 256 Gb solid-state drives commercially available today and experimental drives up to 1.6 Tb available that fit in a 3.5-inch HHD form factor⁴.

There is an important point to consider when looking at storage capacity in terms of the nature of the data being collected in a law enforcement setting. It is naturally tempting to desire the highest capacity media available. This has some apparent advantages, not the least being smaller media management overhead and perhaps convenience. However, one must carefully consider the inherent value of the data being gathered. The information stored can literally mean the difference between a lawsuit, guilt-innocence, etc. Considered in financial terms, the collected video/audio/metadata could *cost or save* an agency tens of thousands of dollars conservatively up to millions of dollars! A high capacity drive can potentially store literally days or weeks of video data, yet one incident that results in damage to the media can result in total data loss. Therefore, one must carefully consider "how much storage capacity do I really need?" and find a suitable balance that minimizes risk yet meets all the other desired criteria as well.

4.2 Cost

Storage media cost comparisons are generally made on a cost-per-gigabyte basis. However, there are a number of potentially relevant factors that must also be considered. Is the capacity of the media appropriate to the amount of daily collected data? For example, if 100 gigabytes represents a typical volume of data and the recording media is DVD±R, slightly more than 20 disks would be necessary per data collecting period. The durability of the media would certainly play a role in cost considerations, i.e., how frequently do the media have to be replaced? Although each

of these storage mediums have manufacturer recommended lifetimes, their basis is established under ideal operating conditions. The general nature of a mobile setting

Table III. MEDIA COSTS

Media Type	Cost per Gigabyte
Magnetic Media:	
2.5/3.5-inch	12¢ to \$4.60
Optical Media:	
DVD +/- R	05 to 13¢
(archival grade)	44¢ to \$1.56
DVD RW	08 to 27¢
DVD +/- R(dual layer)	18 to 51¢
BD - R	18 to 36¢
(archival grade)	88¢ to \$1.09
BD - R (dual layer)	58 to 62¢
BD RE	44 to 90¢
Solid-state Media:	
Compact flash	\$1.96 to \$11.50

Costs reflect the range of average retail prices available in October, 2008.

suggests that at least some time would be spent operating under “non-ideal” conditions, thus having some impact on the lifetime of the media. Do the burners/readers associated with these storage mediums require periodic replacement? Physical size limitations may also play a role in the type of media utilized or perhaps energy consumption requirements. This is just a sampling of the broader issues that should be considered when contemplating cost issues. The range of prices within and between the various storage media shown in Table III are due to a number of factors that will be briefly addressed below.

The range of prices exhibited by magnetic media is primarily due to three points; form factor (size), access speeds, and “ruggedness”. The smaller form factor (2.5-inch) typically cost nearly double per gigabyte compared to the 3.5-inch drives nor do they exhibit the same levels of capacity as that found in 3.5-inch drives (max. 500 gigabytes today). The high end

of the price range is represented by enterprise-level hard drive applications (servers, etc.) where high access rates/throughput is desired. Hard drives that are “ruggedized” to withstand more of the everyday stresses associated with a mobile setting (laptops, etc.) additionally cost a higher premium.

The potentially least expensive media is represented by the optical storage medium. However, their fixed capacities may be a limiting factor, that is, as video resolution demands increase, i.e., consume more storage space, it will require using more thus raising the media management overhead. The archival grade optical media does appear to exhibit greater longevity but is no more durable than the consumer-grade media.

Solid-state media are presently the most costly form of storage medium, however consumer utilization and demand is growing so rapidly and manufacturing innovations are such that their prices are dropping an average of 40-50% a year with trends indicating prices below one dollar per gigabyte by 2011⁵. This is currently the biggest barrier to their penetration into the mass computer industry market except in specialized applications where their performance or durability is of greater importance.

4.3 Longevity

Electronic storage media longevity is a measure of how long data may be

Table IV. MEDIA LONGEVITY

Media Type	Manufacturer stated Lifetime	MTTF (in hours)	Independent Evaluations
Magnetic (HDD)			
3.5-inch form	3-10 years	1,000,000 to 1,500,000	250,000 to 500,000
2.5-inch form		300,000	
Optical			
DVD+/-R	30 – 100+ years	NA	weeks to tens of years
DVD R/W	30 years	1000 write/erase cycles	
BD-R	30 to 200 years	NA	untested
BD-RE	30 years	1000-10,000 write/erase cycles	
Solid-state			
Compact flash	10 years (see text)	2,000,000 to 8,000,000 (see text)	untested

retained on a storage medium before data loss occurs. Broadly defined, it can be thought of as a measure of the durability of a media under ideal conditions.

Unfortunately, this facet of the electronic storage media industry is rather poorly delineated, particularly when attempting to make cross-technology comparisons. It raises a fundamental question that is ambiguously delineated throughout the electronic storage industry; does longevity refer to “how long data may be retained” or to the “operating lifetime” of the media, i.e., its

endurance? All manufacturers have stated claims for their respective media; however problems arise because the relevant industries have yet to establish formal standards or guidelines for evaluating how long data may be retained before data loss. This is further complicated in that the test conditions or evaluation methods utilized/defined under one form of media are not necessarily the same for another. In addition to the lack of clearly established industry-wide tests and measures, most of these storage

technologies are quite young and therefore have not been in existence long enough to provide a true measure of their useful lifetime. Thus companies have conducted accelerated-aging tests to provide experimental data in support of their performance and shelf-life claims for their products. Simply put, memory storage advancements have outpaced their ability to fully characterize them. Hence, the manufacturer-stated-lifetimes shown in Table IV should be regarded with some caution.

The very nature of removable electronic media implies a temporary setting and realistically, no electronic storage medium can be considered permanent, irrespective of its physical longevity, i.e., all media have limited life spans, and for the foreseeable future, there will always be a need to periodically refresh records. Therefore, a more applicable or useful interpretation of longevity might be its endurance or reliability, that is, “how long can one use this media before it fails?” Most of the manufacturers within these respective industries have attempted to address this by providing a measure referred to as “mean-time-to-failure” (MTTF) which represents a gauge of the “useful” lifetime of a product. This is a statistically extrapolated number that is based on accelerated aging test data and thermodynamically-based aging models. This concept is generally misunderstood, with individuals interpreting an MTTF of 1,500,000 hours for example, to mean that the media is reliable for 171 years! A more accurate way to look at this is to state that if 1.5 million hard drives were operating simultaneously, on average one would fail every hour. More realistically, if applied to 100 drives, one would expect, on average, a failure every 15,000 hours. That is equivalent to every 625 days (1.7 years), operating 24 hours a day. A good layman’s description of the vagaries of MTTF can be found in eWeek⁶ or StorageReview⁷ and Seagate Technology offers a good semi-technical article on the statistical derivation of MTTF for those desiring additional understanding⁸.

So how reliable or realistic are these numbers? Unfortunately, there have been only a limited number of studies undertaken by independent groups to evaluate these assessments made by manufacturers. Nonetheless, all these independent studies have consistently shown that the stated lifetimes or reliability assessments were generally shorter than manufacturer-stated claims. This merely suggests that accelerated life tests and statistical extrapolation of this data are poor predictors of actual longevity, although it may still be valuable for indicating lifetime trends under differing environmental/stress conditions. The independent evaluations shown in Table IV are based on these limited studies.

4.31 Magnetic Media

The most comprehensive studies yet undertaken have been within the hard drive industry. This seems quite reasonable given their relative maturity (to the other electronic storage industries) and their vast utilization by business and consumer. The two most comprehensive studies utilized a baseline of 100,000+ hard drives with operational lifetimes of 5 years or less. The study by Carnegie Mellon University found

that the average annual replacement rate was 3% with some systems as high as 13%⁹. This is up to more than fifteen times higher than the manufacturer-rated MTTF claims of 0.55% to 0.88% (an MTTF of 1,000,000 hours equals an annual failure rate of 0.88%). The other large study undertaken by staff from Google, Inc., found that the annual failure rate was roughly 2% for the first year but years two through five saw an average of 4%². The Carnegie Mellon study also found that beyond five years, these failure rates rise considerably with average failure rates of 24% annually. A number of smaller studies have also addressed this issue over the past ten years and they have all presented numbers (3-8%) similar to these larger studies. Obviously, the question arises as to why there is such a discrepancy between the manufacturer and these various field studies. The reader is directed to these large studies which address this to some degree or to a study by Elerath and Shah¹⁰ for a more detailed discussion. Suffice it to say that the manufacturer stated claims are typically based on accelerated aging tests and operating/environmental conditions that may be considered ideal, but not necessarily an accurate reflection of real world conditions.

4.32 Optical Media

Optical media have been readily available for twenty years and one of their most touted advantages has been their claims of longevity. The industry has just established an ISO procedure¹¹ (April, 2008) which provides a formal testing protocol and standard for estimating longevity based on stress evaluations utilizing temperature and humidity conditions. The European Computer Manufacturers Association (ECMA) has also developed a standard for determining longevity of optical media¹². The industry uses accelerated life testing methods to support their life expectancy estimates, but only a number of small independent studies have examined these assertions. These independent groups provide with widely varying results ranging from a few weeks to estimates of decades. However, a limited study conducted by NIST in 2004 found that some DVD media were quite stable and the life expectancy was probably valid for at least several decades, but only under very specific conditions¹³. This same study showed that there was considerable variation between brands and the authors concluded that manufacturing quality and components played a significant role in their durability and stability. An eleven month study conducted by the Library of Congress found that only 47% of the tested DVD's indicated a life expectancy beyond 15 years, and some were as short as 2 years¹⁴. It is apparent that the stress testing parameters used by manufacturers to extrapolate the lifetime of this media are not fully adequate to characterize all the complex variables or threats that may impact optical media longevity. It is evident that the durability of this type of media has a significant impact on its longevity. Even manufacturer-based studies show that minor variations from an ideal setting will impact the projected lifetimes¹⁵. One must additionally realize that manufacturer estimates are based on assumptions that the user practices very careful

guidelines in handling and storing the media. The NIST Special Publication on Care and Handling of CDs and DVDs¹⁶ offers very precise guidelines for maximizing the lifetime of optical media but also clearly state that falling outside these boundaries will have a detrimental impact on life expectancy. The reader should simply be aware that life expectancy estimates of many decades are probably feasible from some manufacturers with one caveat; only under narrowly constrained, *controlled conditions*. This will be further addressed in the following section under media durability.

Blu-ray media represent the latest innovation in the optical storage industry with vastly greater storage capacity than the DVD or CD. It is anticipated to eventually supersede DVD media as the primary distribution means for consumer non-broadcast video distributions. However, this technology is still very much in its infancy (approximately 3 years old) and available lifetime or durability data is currently extremely limited. Because this technology utilizes a shorter wavelength laser for reading-recording data, it is considerably more susceptible to external/environmental hazards than DVD media. These issues will be addressed in the following section under durability. One should simply be aware that at this time, this is an unproven strategy for long-term electronic storage purposes.

4.33 Solid-State Media

If solid state media is used purely for archival purposes, i.e., write once then store it, the data may safely be retained for ten years. Recall that this type of media is comprised of arrays of extremely tiny transistors that each act as an individual memory cell that may hold “data” as a minute electrical charge. Because of their nano-scale geometries and the nature of semiconductor physics, it is possible for this charge (the data) to ultimately “leak” (i.e., data loss) over time. The same physics involved in this process is also responsible for perhaps what most individuals consider the greatest weakness (or concern) pertaining to solid-state media today. There are a limited number of times that data may be programmed/erased (P/E) from this type of media. That is, every time data is written or removed from this form of media, the affected memory cells undergo a degree of deterioration or “wear”. This is what ultimately determines the effective lifetime for *actively* used solid-state media. There are presently two types of storage formats utilized by solid-state media; single-level cell (SLC) or multi-level cell (MLC) designs. SLC-based memory is capable of 100,000 P/E cycles whereas MLC-based memory is capable of 10,000 P/E cycles.

Taken at face value, this would imply that if a single memory cell in an MLC device were erased and programmed every minute, it would wear out in seven days, and an SLC device would only last slightly more than two months! However, manufacturers have developed sophisticated algorithms referred to as “wear leveling” which distribute the program and erase cycles uniformly throughout the media, thus

extending their lifetime considerably. An outstanding description into the nature and intricacies of wear leveling is provided in a white paper published by Imation, Inc. staff in 2008¹⁷. This same report shows how a reasonable estimate of media lifetime becomes a simple calculation if one knows the storage capacity, cycle endurance, and memory usage per day. In their example, if a 32Gb card is fully exploited each day, it would last for approximately 237 years! If ten times that amount of data (320Gb per day) were transferred/erased, the media would still be viable for 24 years! Thus, an absolute estimate of solid-state media longevity is actually an issue of how often and thoroughly it is utilized. Some manufacturers do provide an estimate of longevity based on the amount of data written/erased per day but most simply provide an MTTF, which is ambiguous without knowing how much data is transferred/erased per capacity on a daily basis. One other point that may be important for the reader to understand is that if this media is periodically powered up (once a year for example), the data may be retained for much longer than ten years. Recall that static data may “leak” away beyond ten years; part of the task of these wear-leveling algorithms is to keep the data (i.e., the electrical charge) “fresh”.

The explosion in solid-state media utilization throughout the consumer market and its expansion into the IT and computer industry as embedded or stand alone systems has led to an even greater need to certify the longevity/reliability of this media. Manufacturers are attempting to address this need and SanDisk recently proposed a metric referred to as the “Longterm Data Endurance” (LDE) which would provide a measure of the total number of terabytes a solid-state media can write in its life¹⁸. Although the solid-state industry has yet to formalize any standards, they will be coming soon.

4.4 Durability

Broadly defined, durability is simply a measure of the range of environmental or operating conditions a media can withstand and still function properly. This ambiguous statement suffers under many of the same issues as addressed on media longevity. Unlike “longevity” which can be thought of as a measure of the durability of a storage media under “ideal” conditions, this parameter represents those boundary conditions or extremes that will ensure failure. In the context of this paper, our interests are focused on the response of these various memory storage mediums to the range of situations that may be experienced in the diverse setting of a mobile environment. Like the characterization of longevity, most of the specifications shown in Table V. are based on manufactured established evaluations.

Table V. Media Durability

Media Type	Operating temperature range	Relative Humidity	Vibrational stresses (operating conditions)	
			shock	Continuous
Magnetic Media:	5 to 55°C	5 to 90%	Up to 70 g's	0.5 to 2 g
“ruggedized”	-40 to 70°C (with heater)	0 to 100% (non-condensing)	Up to 300 g's	up to 8 g (with isolation systems)
Optical Media:				
DVD	-20 to 60°C	5 to 95%	10 g	1 g
“archival”	4 to 20°C	20 to 50%	?	?
Blu-Ray	5 to 55°C	3 to 90%	?	?
Solid State Media:	0 to 70°C (consumer)	4 to 96%	1,500-2,000 g's	
Compact Flash	-40 to 85°C (industrial)		20 g's	
			2,000 to 3,000 g's (industrial)	

4.41 Magnetic Media

From an engineering and manufacturing viewpoint, the hard drive truly represents an astounding piece of equipment. Consider that the average distance of the read/write head above the disk platter is on the order of a few nanometers (that’s several thousand times smaller than a human hair) with the platter spinning an equivalent of 40 to >150 mph (depending upon platter diameter and rpm) yet never coming into contact! We take for granted how durable and reliable this media is considering these standard operating conditions. However, this still represents their greatest vulnerability when considering the typical (and potentially extreme) vibrational stresses that may be encountered in a mobile setting. If the read/write head comes into physical contact with the disk while it is at operational speed (spinning several thousand rpm), the minimum result can be limited data loss, damage to the read/write head,

damage to the surface of the disk, or all three. Most manufacturers have a thin protective film on the surface of the disk designed to tolerate some degree of abuse, yet scratches generate particles and generally, the likelihood of another “head crash” increases dramatically due to particle contamination. Many hard drives have built-in protective measures that upon detecting stresses above a certain level, the head moves into a protective position. Obviously, data loss may occur at these times depending upon the size of the memory buffer built into the drive. Until relatively recently, the hard drive was the primary storage media used in military/avionics applications as event recorders (black boxes) but is now being superseded by solid-state media. The only exceptions being those cases where extremely large storage capacity is still needed.

4.42 Optical Media

As discussed earlier under longevity, the basis of most assessments concerning optical media has been through accelerated life (stress) testing. These stress tests are designed to estimate the life span and durability of a product under “normal” use based on the wear and tear it undergoes by exposing it to extreme levels of stresses. Relative humidity and temperature have been the primary environmental stress factors utilized, yet it is clear there are other variables involved. The 2004 NIST study on optical media discussed previously found that exposure to UV radiation (sunlight) could have a profound impact on the media longevity shortening the lifetime to a matter of weeks. It should be noted that no other electronic storage product uses a bare media format and perhaps one of the greatest vulnerabilities of optically-based storage media is the fact it must be directly handled to some degree. The “intangible” factor of handling can be a major cause of media deterioration and/or reading-writing errors (due to scratches, etc.) and it has been essentially impossible for the industry to fully characterize (quantify) this feature. One unusual study carried out by an Australian consumer advocacy agency examined the durability of this media (CD’s & DVD’s) to the physical stresses (bending) it encounters when being removed from its protective case¹⁹. They took each sample through 2000 bending cycles simulating what a media might perhaps experience during its lifetime. Repeated flexing can develop cracks around the center and because this media rotates (up to 10,000 rpm), these cracks can grow or even result in the disk shattering in extreme cases. Their study found 4.5% of the DVD media were rendered unreadable either due to breaking or extensive cracking, and an additional 32% of all the media tested (CD & DVD) had begun to show visible cracks. This just represents another example of the potential vulnerabilities inherent to bare media. Most users of this form of storage are aware of these potential weaknesses and typically compensate by maintaining multiple copies. Although this may be an effective strategy, it adds dramatically to the media management overhead and costs.

Blu-ray media could significantly impact issues such as media overhead due to its greater storage capacities. However, as briefly stated in the preceding section under

longevity, this media does not yet have a track record, and its suitability as a recording medium under the conditions that may be experienced in a mobile environment are presently unknown. These concerns arise because this technology utilizes a shorter wavelength laser (blue) enabling it to record/read to much finer geometries on the substrate (hence the ability to store more data). This, in turn, requires considerably higher laser precision, mechanical stability, surface cleanliness/scratch resistance, and disk rigidity than is needed for a DVD. The various BD manufacturers have attempted to address many of these issues by developing proprietary “hard-coat” technologies, creating thicker substrates to deal with potential warping, and even the application of protective coatings to shield against UV (sunlight) degradation.²⁰ In spite of these (and other) manufacturing improvements, some question the suitability of this media for even archival purposes.²¹ It fundamentally comes back to the uncertainties inherent to bare media formats and the potential vulnerabilities this introduces. Furthermore, there is currently no data to suggest this media/drive could withstand the daily strains and potentially extreme vibrational stresses that would be encountered in a mobile environment.

4.43 Solid-State Media

As discussed under longevity, perhaps the greatest shortcoming of solid-state media at present is the limited number of write/erase cycles that may occur, or what is also commonly referred to as its “write endurance”. Wear leveling algorithms have done much to minimize this limitation and continued improvements in the technology will probably soon remove it from consideration. Samsung, for example, just recently announced (July, 2008) the development of single-level cell (SLC) flash memory that offers a fivefold increase in its write/erase endurance (500,000 P/E cycles)²².

Perhaps the most lauded asset of solid-state media is its “ruggedness”. Unlike magnetic and optical storage technologies which involve moving parts in at least part of their operation, this media contains no moving components. Hence, it’s vastly superior ability to sustain a much greater range of environmental stresses with no impact on its performance. In a mobile setting, this is perhaps the single most significant unpredictable variable that can impact the ability to record live video. The “lack” of moving parts additionally gives solid-state media some other unique advantages and superior features; quiet operation, fast read/write speeds, low power consumption, as well as compact and light form factor. It is actually many of these latter features that are driving their market growth and demand in the IT industry. Because of these attributes solid-state media is today the preferred storage format utilized in military/avionics applications as event recorders (black boxes) and in space applications. The only exceptions being those cases where extremely large storage capacity is still necessary.

4.5 Obsolescence

All of these electronic storage technologies are well established in the market place. The question and challenge becomes one of predicting the relentless and fast-paced trends of these technologies. Consider, when was the last time you saw a computer with a 3.5-inch floppy drive? Ten years ago these were still standard components in most computer systems. When was the last time you saw an operating 5.25-inch floppy? – a standard component merely 15-20 years ago. This raises the question of just how long is really practical for long-term storage within a particular technology. The incredibly dynamic and rapid advances ongoing throughout much of the electronics industry suggest that technological obsolescence may conceivably be of greater significance than the longevity of the storage media itself. Consumer and market demands see no abatement in this trend for the immediate future. Selection of an existing storage media that is most compatible and readily transferable to these newer technologies would be most desirable. Speculation on the future of the electronic storage media industry is just that, “speculation”, however, considerable effort is spent by vendors, buyers, and manufacturers in anticipating future electronic storage trends.

4.51 Magnetic Media

This industry is deeply entrenched in the business and consumer markets. Currently, their most distinct and valuable asset is their large storage capacities. This one feature gives them a unique advantage over all other forms of electronic storage because certain industries need or desire these capacities and the industry intends on increasing this capability into the foreseeable future. As briefly mentioned earlier, the magnetic media industry plans on having 2 terabyte drives available by 2009 and anticipate 50 terabyte capacities sometime in the first half of the next decade. However, some market analysts foresee a shift in their market sector. Hitachi is predicting their magnetic media market will begin to decline in 2010 with an increase in solid-state drive demands. They anticipate that the solid-state drive will replace the high end market of the magnetic hard drive sector (networks, servers, etc.)^{23,24} where speed, throughput, power consumption are issues. However, they see the demand for HHD's in consumer systems (DVR's, home computers, etc.) to increase, where performance concerns are not as great an issue. This media is safely established for the foreseeable future but SSD's are anticipated to take larger and larger market shares if their cost continues to decline.

4.52 Optical Media

The Optical media market is surmised to have a safe future for at least the next several years, primarily serving the consumer market as it does today, distributing entertainment content, and storing personal data. The industry is planning on

developing and offering higher density media yet some debate whether there will be a market or need beyond perhaps ten years²⁵. The driving dynamic of optically-based storage is the consumer, and as the consumer realizes that they may pack their entire entertainment library or storage needs into a smaller, more mobile form factor they will do so. This will be guided by at least two issues; as advances in communications technology and wireless networking increase, internet download may become the primary distribution means for entertainment-type content. Some speculate consumers will favor walking into a store and purchasing entertainment by having it copied to their preferred solid-state media. Store owners would like this because it means having zero inventories. Secondly, removable media exchange will be most likely be dominated by those forms which are compatible across the widest range of consumer merchandise, that is, pocket consumer products (cell phone, PDA, etc.) and desktop systems²⁶. The optical storage format has represented a cost effective mass-market consumable that has filled a consumer niche but is being seen by more and more as a transitional stepping stone (not unlike the floppy drives) that will shortly be superseded by more efficient and convenient media storage choices²⁷.

4.53 Solid-State Media

The solid-state memory market is growing faster than any facet of the electronics industry in the history of semiconductors⁵. Their growth and utilization into the mass consumer electronic products and the telecommunications sector assures their dominance as the primary removable/portable storage media into the foreseeable future. Some market analysts predict that solid-state media will eventually dominate the mobile market, replacing the 2.5-inch hard drive and continue to expand into the enterprise server/network market where its performance advantages outweigh current cost factors. How much of the electronic storage market becomes dominated by solid-state media will ultimately be determined by cost competitiveness.

5. Conclusion – What’s Best?

How does one objectively choose the best electronic storage medium for a mobile environment setting? The first and foremost concern should be the accurate documentation, preservation and reproduction of events. Secondly, due to the unpredictable nature of environmental conditions and stresses that may be associated (or created) within the confines of a mobile setting, it seems reasonable to assign a high priority to that media which exhibits the greatest overall durability or best “survivability” under the widest range of foreseeable conditions. Considering this alone it is clear that solid-state media is the superior choice. However, questions such as budgetary constraints or media back-office management concerns, to name but a few possible examples, may change the relative priorities of the criteria that have been discussed in this paper. A simple comparison table might provide an effective means to impartially

contrast these electronic storage media based on the criteria that have been discussed. Each criterion will be assigned a simple rating corresponding to; 1- Good, 2- Average, 3 – Poor, for each of the media types. The most ideal media would have a total rating close to 5 and the poorest would be closest to 15. The following results are presented;

Media Type	Storage Capacity	Cost	Longevity	Durability	Obsolescence	Total
Magnetic media	1	1	3	3	1	9
Optical media	3	1	1-2	3	2	10-11
Solid-state media	1-2	3	1	1	1	7-8

- 1) Optical media is the least suitable storage medium of all available choices;
 - Least durability for mobile environmental conditions.
 - Questionable longevity when tied in with durability issues.
 - Storage capacity is currently the smallest available.
 - Questionable future (will it be around in 5-10 years?)
- 2) Magnetic media is a viable option. Until recently, this represented the most typical storage media of choice. However, it suffers from two fundamental weaknesses;
 - Durability is limited for the range of conditions one would anticipate in a mobile setting.
 - Longevity is poorest of all available media.
- 3) Solid-state media is the most suitable choice for maximizing the likelihood of data integrity under the widest range of operating conditions. Currently, its weakest point is;
 - Cost. However, as pointed out earlier, industry trends indicate this media is dropping roughly 50% annually.

- Some might suggest storage capacity as a shortcoming. However, the growth of this industry in storage capacity is anticipated to double annually for at least the next five years.

Solid-state media is the best choice between the existing electronic storage formats commercially available today based on the criteria used in this document. Moreover, the ongoing technological improvements and innovations driving this industry and its rapid adoption by consumer and business alike indicate this will likely become the preeminent form of electronic storage for the future.

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