Unlocking the DCP:

Evaluating the Risks, Preservation, and Long-Term Management of Digital Cinema Packages in Audiovisual Archives

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I. Introduction

The changeover from analog film to digital cinema projection represents the single greatest shift in theatrical exhibition since the advent of sound in the late 1920s. Central to this change is the Digital Cinema Package[1], a discrete ensemble of digital files that must be unencrypted and de-compressed onsite in order to play its embedded content. In the arena of commercial film distribution and exhibition, DCPs are, for all intents and purposes, equivalent to a 35mm theatrical release print.

With digital cinema slated to grow exponentially over the next several years in theatres both domestically and abroad, the presence of DCPs in adjacent audiovisual archives will continue to increase. Consequently, the ability to properly preserve DCPs and make them accessible in the long-term will become of paramount importance to archives worldwide.

However as this thesis will demonstrate, DCPs are complex entities that present preservationists with a series of challenges. Some of these issues—most notably those surrounding encryption, competing specifications, and errors inherent to the software used to create DCPs—are unique to the format and will require a distinct approach, while others apply to digital preservation more broadly. The challenges that fall within the latter category include rapidly evolving specifications, hardware and software dependencies, and concerns surrounding the JPEG 2000 and MXF standards, among others. These problems are already largely familiar to digital archivists, but a discussion of these problems within the context of DCPs will highlight the extent to which active and continual stewardship will be required to ensure that DCPs and other digital media are accessible in the long-term.

In her pioneering book, *From Grain to Pixel*, Giovanna Fossati addresses her decision to write about film's ongoing technological transition from analog to digital while it is still taking place. Fossati claims that the first reason, "concerns the value of a historical record of events still taking place," while "the second resides in the possibility of exercising some kind of influence on the direction events are taking in the practice, in this case the practice of archiving and film preservation."[2] This thesis was deeply influenced by Fossati's rationale, particularly with respect to her second motive. However while Fossati's goal is to interrogate this transition from a theoretical perspective in an attempt to "[provide] a common ground for a renewed dialogue between film archives and media studies,"[3] my project examines the transition from a technological point of view, and is aimed at providing archivists with a resource that may inform their decision making about the long-term care of DCPs.

The impetus for this thesis was the scarcity of research that addressed the long-term preservation of DCPs. Despite the fact that the first set of standards for this format were formally adopted by the Society of Motion Picture & Television Engineers seven years ago, there has been a dearth of investigation into the archival challenges specific to this format,

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[1] Hereby known as "DCP."

[2] Giovanna Fossati, *From Grain to Pixel: The Archival Life of Film in Transition* (Amsterdam: Amsterdam University Press, 2009), 20.

[3] Giovanna Fossati, *From Grain to Pixel: The Archival Life of Film in Transition*, 16.

and how film archives must adapt in order to address these problems. There are several reasons why this may be, but the primary cause of this is likely connected to the fact that until the late 2000s, film exhibitors were resistant to making the substantial investment required to install digital projectors. The limited number of screens equipped for digital cinema projection inhibited a wholesale adoption of the format, in spite of its standardization. The gradual rate of adoption delayed the appearance of DCPs in film archives, which in turn rendered the need to closely examine the characteristics of this format a secondary priority.

Another reason that there does not yet exist a larger body of research on the subject may be that the standards for DCPs are continuously evolving. Since they were formally adopted in 2006, the standards that detail the technical specifications for DCPs have been continuously updated and amended, and the rate at which these guidelines have evolved over the intervening years may have been a disincentive to investigating the format's long-term viability.

Finally, although the advent of the DCP generated significant discourse surrounding the subjects of distribution and exhibition, these discussions have focused primarily on ontological and historiographical questions rather than archival concerns. As demonstrated by Fossati, these debates bear significant weight on the "archival life of film"[4] and demand deeper consideration from archivists and scholars alike. However, despite their relevance to many facets of archiving and preservation, the theoretical questions surrounding film's transition from analog to digital has thus far overshadowed discussion about—and consequently investigation into—the archiving and preservation of DCPs in the long-term.

All of the above are valid reasons why significant research and discussion surrounding the preservation and access of DCPs has not yet emerged. However, due to the rapid adoption of digital cinema projection and subsequent influx of DCPs in archives around the world, examining these issues has become critical. My thesis will investigate the various challenges associated with archiving and preserving DCPs, outline a series of recommendations addressing these issues, and examine what this will mean from a practical point of view for film archives henceforth. To do this, I will first provide a historical frame of reference for DCPs by briefly discussing the advent of DCPs and the events leading to the format's standardization. This section will provide an account of the format's origins and contextualize the considerations, particularly with regard to the film industry's fears surrounding piracy, which governed the implementation of a systems architecture designed to restrict access.

Once I discuss how DCPs came into being, I will provide a granular analysis of its component parts and the processes through which a set of audio, video, and text files become conformed to a DCP's specifications. This section will act as a resource for readers by providing accurate, accessible definitions of the various elements found within a DCP.

[4] Fossati defines "the archival life of film" as "[indicating] the life of film once it has entered the archive, from selection to preservation, from restoration to exhibition and digitization." Fossati, *From Grain to Pixel: The Archival Life of Film in Transition*, 23.

Identifying the assets, file structure, and metadata that comprise a DCP will both allow for a deeper understanding of the format, and will enable an in-depth examination of the risks carried by its components parts.

Like standard 35mm release prints, DCPs will typically arrive at audiovisual archives after their theatrical run is complete, and the following section will address the growth of digital cinema exhibition over the past decade that precipitated the appearance of this format within collections around the world. This will provide a backdrop for a discussion about the presence of DCPs in archives. This section will include descriptions of the acquisition policies surrounding DCPs, observations regarding where workflows relating to the ingest process for DCPs either overlap or differ across institutions, and some of the current preservation models in use with regard to this format. Based on a series of interviews conducted throughout the first quarter of 2013, this section of my thesis will provide a snapshot of film archives during a moment of transition by detailing how several key institutions are currently approaching this format and its attendant risks.

The next section will detail these risks at length. They include risks specific to the use of JPEG 2000 and MXF standards; formatting concerns; the vulnerable nature of the carrier on which DCPs reside; unstable and continuously evolving standards; the use of encryption; problems surrounding versioning; and issues involving the color gamut of the DCP's associated projection technology.

After discussing all of the risks surrounding DCPs I will offer a series of recommendations that will mitigate these issues. Based on the interviews I conducted in addition to my own research, these recommendations will help archives safeguard this format over the long-term, and will serve as a reference for film archives seeking a comprehensive overview of the considerations required for the preservation of DCPs. These recommendations will ultimately bring to light some of the larger concerns raised by this format, and in my final section I will discuss the impact of DCPs on the preservation community at large and address what archives must understand about this format going forward.

II. History of DCPs: Advent and Standardization

The Introduction of Digital Technology

35mm motion picture film has proved to be a remarkably stable recording medium. In fact, writing in 2005, Leo Enticknap explains that "standard 35mm proved to be ideally suited for conventional cinematography and auditorium projection, so much so that (with a few minor variations) this format is still being used for this purpose [today]."[5] Therefore David Bordwell's observation in *Pandora's Digital Box: Films, Files, and the Future of Movies*, that "cinema was the last medium in popular culture to go fully digital"[6] should come as no surprise. Indeed, while the music industry, publishing houses, and consumer and professional photographers alike had already begun moving toward digital technologies in the late 1980s and 1990s, it took the film industry over three decades to complete the process of conversion from a wholly analog to an exclusively digital environment.

Hybridized Workflows

The piecemeal changeover to digital began in the realm of post-production during the 1970s with the introduction of non-linear editing systems and computer-controlled effects.[7] Over the course of the next two decades, digital technology continued to work its way into the creative process, offering the director unprecedented control over the final look and sound of a film. The aforementioned technologies, alongside Computer Generated Imagery (CGI), digital sound processing, and a color timing procedure called the Digital Intermediate (DI) process,[8] quickly became ubiquitous components of post-production workflows, and their widespread popularity helped create an alterity for the industry to traditional video and film workflows.[9]

The gradual integration of digital technologies throughout the 1980s and 1990s gave rise to a hybridized production system that combined traditional photochemical and analog processes with digital technology at varying points in the creative process. Within this system, Hollywood films were typically shot on 35mm film and then scanned at a high resolution to yield a digital video file. The creation of this file would allow the film to be

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5 Leo Enticknap, *Moving Image Technology: From Zoetrope to Digital* (London: Wallflower, 2005), 73.

6 David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies* (Madison, WI: Irvington Way Institute Press, 2012), PDF E-book, 25.

7 Here it must be noted that digital cinema's roots in fact belong in the field computer graphics, and any discussion of the history of digital technology in the film industry must acknowledge the pioneering experiments conducted during the 1950s and 1960s by computer scientists—most notably by those working at Bell Laboratories—that sought to harness the creative capacity of digital mainframe computers. Although the scope of this thesis does not permit a deeper analysis of these experiments and the integral role they played in laying the foundations—both technological and aesthetic—for digital cinema, the subject is important to note and deserves much deeper consideration by film scholars and historians alike. For an expanded discussion of this subject, see: Shira Peltzman, "'Visualizing the Invisible:' An Alternative Historical Narrative and the Technological Roots of Computer Animation" (Unpublished paper, Tisch School of the Arts, New York University, 2012), 4-10.

8 Although the DI process allowed film to be scanned and manipulated digitally, the digital file that resulted would typically be output to film, thus making it a hybrid photochemical/film process.

9 Charles S. Swartz, *Understanding Digital Cinema: A Professional Handbook*, (Amsterdam: Focal, 2005), 39.

constructed in the digital realm, where it could be easily manipulated during post-production. Ultimately a "digital master" file would be produced, which would then be output back to 35mm film for a theatrical release.

But this model was inefficient; digitizing 35mm film took up both time and money.[10] Many saw enormous creative, logistical, and financial advantages to an entirely digital workflow, the price of which was quickly becoming more affordable due to the falling price of storage and processing power.[11] As the popularity of digital mastering grew, and as technological milestones in adjacent fields were reached,[12] many within the industry began to look toward a viable digital workflow that seamlessly integrated the various stages of the production, distribution and exhibition processes.

Foremost among this group was George Lucas. From the beginning of his career, Lucas had been involved in the development of cutting-edge technologies as tools of expression, and he had become convinced that the future of filmmaking depended upon developing an all-digital workflow. In 1996 Lucas began discussions with Sony to pursue the development of a digital motion picture camera that would be capable of producing an image with a quality commensurate with 35mm film, and which could pave the way for the eventual development of a tapeless workflow.[13]

Arrival of HD Progressive Digital Motion Picture Cameras

At Lucas' behest, after four years of research and development Sony debuted the HDW-F900 digital 24p CineAlta camera in 2000, marking the first time it was possible for Hollywood filmmakers to capture and store High Definition progressive digital video images. The F900 was an instant success—it was met with excitement across the industry and quickly integrated into the workflows of several major Hollywood productions. Competitors instantly seized upon and began to improve Sony's model, releasing a barrage of competing progressive digital video cameras in the subsequent years.

Here it is important to note that in spite of digital cinema's myriad advantages—including significantly cheaper operating costs, higher shooting ratios, smaller physical storage requirements, fast transfer rates, and the capability of immediate playback—Hollywood has yet to embrace the medium completely. This is due in part to a number of factors, including the enduring aesthetic of film in addition to the relative difficulty and higher cost

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[10] According to a 2002 estimate, the DI process alone could cost between $180,000 and $240,000. Freddy Goeske, "The Digital Intermediate Process," Indie Producing, November 23, 2002, section goes here, accessed February 13, 2013, http://www.indieproducing.com/digital_tech_archives/intermediate.html.

[11] Brian McKernan, *Digital Cinema: The Revolution in Cinematography, Postproduction, and Distribution*, (New York: McGraw-Hill, 2005), 40.

[12] The research and development of digital video technology was also due in large part to the skyrocketing popularity of commercial digital still cameras, which in turn fuelled advances in bit-depth and bit-mapping. For example, in 1995 alone, more than 35 new digital cameras models were released worldwide; the following year, the number of new models introduced increased to 67; and in 1997, there were an additional 156 new models introduced. Michael R. Peres, *The Focal Encyclopedia of Photography: Digital Imaging, Theory and Applications, History, and Science*, (Amsterdam: Elsevier/Focal Press, 2007), 17.

[13] McKernan, *Digital Cinema: The Revolution in Cinematography, Postproduction, and Distribution*, 28.

of preserving digital objects. Nevertheless, in spite of vocal resistance from industry creative leaders like Christopher Nolan,[14] digital cinema has made an enormous impact on the field and threatening the continued use of 35mm film, leaving the future of the medium uncertain.[15]

Developing a Viable Delivery System for Digital Cinema

The arrival of High Definition progressive digital motion picture cameras cemented the widespread adoption of an entirely digital production and post-production workflow, ensuring that theatrical digital cinema distribution and exhibition would become inevitable. However by the early 2000s, the technology available to create digital cinema had outpaced the creation of a viable method for its delivery. Solving this problem became a paramount concern for the distribution wing of the film industry, for which a digital delivery system would offer enormous advantages.

As Bordwell notes, "besides saving money on prints and shipping—the public rationale for the switch—distributors could now monitor the number of screenings at any venue,"[16] which it was hoped would reduce the opportunity for piracy. In addition to allowing for a greater degree of control over their intellectual property, the principal benefit sought by the studios from a changeover to digital distribution would be the opportunity to exert control over exhibition. According to Bordwell, this would serve to, "[keep] competitors off screens, [yield] more or less assured revenues, and [allow] vast economies of scale."[17]

In anticipation of the arrival of digital cinema, these parties began conducting a series of "one-off tests and experiments"[18] throughout the 1990s. These trials included delivery mechanisms that ranged from satellite delivery to streaming via fiber optic cables. However in terms of both network speed and security, none of these delivery schemes had been met with much success.[19] The option that offered the best results, and which quickly became the de facto delivery method, involved uploading files onto a hard drive and shipping the drive directly to a theatre for projection.

Given the technological limitations, designing the physical components of a delivery schema for digital cinema was a relatively simple task: in the absence of a superior technology, a hard drive containing a set of digital files provided the blueprint for what would eventually be standardized as the DCP. However the major obstacle facing digital

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[14] Alex Ben Block, "'Dark Knight Rises' Director Christopher Nolan Isn't a Fan of Digital," The Hollywood Reporter, June 9, 2012, accessed February 08, 2013, http://www.hollywoodreporter.com/news/dark-knight-rises-chris-nolan-digital-335514.

[15] Matt Goldberg, "ARRI, Panavision, and Aaton Cease Production of Film Cameras; Will Focus Exclusively on Digital," Collider, October 12, 2011, accessed February 16, 2013, http://collider.com/film-camera-production-ended-arri-panavision-aaton/120103/.

[16] Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 69.

[17] Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 48.

[18] Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 34.

[19] Matt Rothman, "Digital Tech Points to Pix' Future," *Daily Variety* (Los Angeles, CA), May 12, 1992.

distribution and exhibition was a pervasive fear of piracy, which was presented a palpable threat to content creators, distributors, and exhibitors alike.

A Long History of Piracy

Piracy has been a perennial problem in the film industry since its advent. It has taken many forms over the years, from exhibitors illicitly making duplicate negatives of rented prints in the early 1900s to consumer redubbed VHS tapes in the 1990s.[20] For most of the twentieth century, however, there were two principal barriers that prevented piracy from becoming a substantial threat to studios. First, making a duplicate copy of analog content requires special skills and equipment. Until the introduction of VHS in the late 1970s, the average consumer would not have had neither the skillset nor the access to professional-grade equipment that pirating films would have necessitated.

Additionally, when an analog film or video is duplicated, the copy will not be identical in quality to the original. "Generational loss" is a term that describes the loss of quality (i.e., the introduction of fading and a loss of resolution) that occurs during the duplication process between subsequent copies of a film or video. Each time a copy of an analog source is made, explains film scholar Holly Willis, "some of the original information fidelity or precision is lost in the process of transcription, causing image quality to suffer and limiting the number of copies that can be made."[21] The significantly lower quality copy, albeit acceptable on a basic level, are markedly inferior, and therefore have limited value.

The Threat of Digital Piracy

However, digital films are fundamentally different from their analog predecessors in this regard. As Willis explains, "a digital camera does not record an analog signal of continuously varying voltages but instead a series of zeroes and ones in a pattern of relationships defined by mathematical algorithms. … As a result, digital information may be endlessly duplicated."[22] With no discernible difference between an original file and its subsequent copies, a digital file has the capacity to be infinitely reproduced with no loss of quality.

Thus, in spite of its low resolution (352 x 240 pixels), when the VCD—a cheap digital format that allowed video to be stored on optical discs—was launched in 1993, it instantly became "a perfect medium for piracy" because it allowed files to be replicated quickly, cheaply, and exactly.[23] VCDs were, claims Bordwell, "the answer to a film pirate's prayers" because this format enabled mass production of copies that were identical in quality to the

[20] For more on this subject, see Kerry Segrave, *Piracy in the Motion Picture Industry*, (Jefferson, NC: McFarland & Co., 2003), which provides a thorough survey of piracy in the film industry from its inception to 2001.
[21] Holly Willis, *New Digital Cinema: Reinventing the Moving Image*, (London: Wallflower, 2005), 6.
[22] Holly Willis, *New Digital Cinema: Reinventing the Moving Image,* 6.
[23] "VCDs Killed the Kung Fu Star," *The Economist*, March 18, 1999, accessed February 16, 2013, http://www.economist.com/node/319898.

original source.[24] Moreover, VCDs were cheaper, more portable, and easier to use than the technology (VHS tapes) that preceded it.

Throughout the 1990s piracy rates soared worldwide, flourishing at even greater rates within developing economies.[25] In 1997, the introduction of the DVD only worsened the situation; with a resolution over twice that of the VCD (720 x 576 pixels), DVDs provided pirates with access to higher quality source material. Although protection devices were applied to both of these formats to safeguard the valuable intellectual property they contained, Bordwell notes that, "cracking the security encryption was literally child's play"[26]—a mere seven lines of code were all it took to crack the Contents Scramble System (CSS) security used to protect DVDs,[27] which meant that piracy continued to thrive, unabated by the measures to prevent it taken by electronics manufacturers.

Peer-to-Peer Networks

Compounding this problem was the advent of peer-to-peer (P2P) file sharing networks. Although the principle behind peer-to-peer networks—the technology enables users to upload and download files from one another by allowing their machines to connect directly—had been in use for over two decades, the emergence of websites, including Napster in late 1999 and KaZaA and Gnutella in early 2000, which had been specifically designed to facilitate media piracy, was novel.

Their appearance was precipitated by the increasing speed of internet connections coupled with the recent introduction of file formats like MP3 and MPEG-2, which allowed large video and audio files to be compressed into smaller, more manageable files that were easier to download. Both because P2P networks provided a simple, fundamentally de-centralized way for users to swap increasingly high quality digital media files and because they are difficult to police, the popularity of this technology skyrocketed in the years following its introduction. Therefore, when the changeover to digital distribution and exhibition became a reality, piracy was the foremost among the studios' anxieties.[28] The studios expressed concern that if pirates were successfully able to steal and distribute a big budget film—especially before its theatrical release—the losses would be enormous.[29]

The Need for Appropriate Security Measures

According to Bordwell, "the new system would have to be airtight. A film would have to be secured in transit and during its time in the projection booth. There would also have to be

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[24] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 39.

[25] Joe Karaganis, *Media Piracy in Emerging Economies* (New York, NY: Social Science Research Council, 2011), 10.

[26] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 39.

[27] Sam Costello, "Seven Lines of Code Can Crack DVD Encryption," PCWorld, March 8, 2001, Consumer Advice, accessed February 16, 2013, http://www.pcworld.com/article/43943/article.html.

[28] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 33.

[29] Matthew Belloni, "'Wolverine' Pirate Pleads Guilty to Copyright Infringement," The Hollywood Reporter, December 19, 2011, accessed February 16, 2013, http://www.hollywoodreporter.com/thr-esq/x-men-wolverine-pirate-sentenced-hugh-jackman-275453.

some identification of the unique copy, in order to trace [the production of] any auditorium versions."[30] The security measures that had been put into place on previous consumer digital formats like the VCD and DVD would not suffice. According to John Fithian, head of the National Association of Theater Owners (NATO), in order to allay the misgivings about digital cinema voiced by many across the industry, the security measures would have to meet studios' stringent demands; without their unanimous support, the possibility of a large-scale digital rollout would be impossible.[31]

However producing a set of "airtight" security measures for digital cinema could not be done on a piecemeal basis. It quickly became clear that in order to assuage fears surrounding piracy, a rigid set of standards for digital cinema would have to be developed.

The Development of Standards

In addition to the perceived threat of piracy, there was another reason that developing standards for digital cinema was becoming a paramount concern: After it had become apparent that storing digital cinema on protected hardware would provide the best solution, studios and distributors co-opted with purveyors of digital storage and protection technology to create a product that serviced the needs of both. However, the rapid proliferation of competing product designs, compression schemes, and file formats in use in the early 2000s created significant confusion, making the distribution and exhibition of digital cinema a complicated endeavor and highlighting the necessity of professional standards.

SMPTE's Early Attempt

The Society of Motion Picture & Television Engineers (SMPTE) had anticipated this scenario, and citing a mutual desire for standards from both content creators and exhibitors,[32] had begun to draft a set of recommendations for digital cinema as early as 2000. However, their task was made difficult by the range of products available coupled with a lack of user input, which, according to digital cinema consultant Michael Karagosian, lead to "a manufacturer-driven market, where each manufacturer [hoped] to gain sufficient market share in an effort to claim they [were] a de facto standard."[33] Although SMPTE's efforts provided the genesis for a set of industry standards,[34] the uniform technical specifications that Hollywood ultimately adopted grew out of an effort put forth by the

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[30] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 57.

[31] Scott Kirsner, "The Talk of ShowEast: Piracy, Digital Cinema, Hurricanes," CinemaTech, October 26, 2005, accessed February 16, 2013, http://cinematech.blogspot.com/2005/10/talk-of-showeast-piracy-digital-cinema.html.

[32] Society of Motion Picture & Television Engineers, *Status Report: D-Cinema Technology Committee (DC 28)*, report (Los Angeles, CA: Society of Motion Picture & Television Engineers, 1999), https://www.smpte.org/sites/default/files/files/DC_Belmer.pdf.

[33] Michael Karagosian, "New Studio Coalition To Look Into Standards: NewCo Digital Cinema: Tech Issues Come Home to Roost," National Association of Theatre Owners: In Focus, June 2002, accessed March 04, 2013, http://www.natoonline.org/infocus/02June//digital.htm.

[34] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 53.

Digital Cinema Initiatives (DCI), a limited liability corporation formed by representatives from the major Hollywood studios themselves.[35]

Digital Cinema Initiatives, LLC

The DCI was established in March 2002, with a stated goal "to establish and document voluntary specifications for an open architecture for digital cinema that ensures a uniform and high level of technical performance, reliability and quality control."[36] In meeting this challenge, the DCI had to satisfy three principal objectives: streamlining the technological requirements, ensuring consistency of performance, and agreeing upon security precautions that would effectively guard against piracy.[37] The DCI's standards were to serve as the industry benchmark. Subsequently, the DCI was well aware that if they did not adequately fulfill the above criteria, their recommended standards could not be universally adopted.

In December 2002 the DCI initiated a series of field trials, naming the Entertainment Technology Center at USC's Digital Cinema Laboratory as the designated site to test digital cinema technologies. Described as a neutral research center funded by Hollywood studios and high tech companies that would be "dedicated to evaluating new entertainment technologies," the Entertainment Technology Center was tasked with providing the research for a set of industry standards that would be, "scalable into the future."[38]

By November 2003 the DCI issued a press release announcing the members' unanimous support for some initial features (most significant among them were 2K/4K backwards compatibility),[39] and in July 2005 they released the Digital Cinema System Specification version 1.0. Although voluntary, the DCI's System Specification, updated regularly since its initial publication, has effectively set the industry standard for digital cinema system concepts, compression, packaging, transport, projection, and security. Large sections of the specifications in this document have been adopted as SMPTE standards,[40] and as such the

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[35] Disney/Buena Vista, Twentieth Century Fox, Paramount Pictures, Sony Pictures Entertainment, Universal, and Warner Bros. An initial member, MGM withdrew its membership in May 2005, prior to the completion of the System Specification. Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," Digital Cinema Initiatives, March 7, 2008, accessed February 16, 2013, http://www.dcimovies.com/archives/spec_v1_2_No_Errata_Incorporated/DCIDigitalCinemaSystemSpecv1_2.pdf, 15.

[36] Digital Cinema Initiatives, LLC, "About DCI," Digital Cinema Initiatives, accessed February 16, 2013, http://www.dcimovies.com/.

[37] Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 57.

[38] Digital Cinema Initiatives, LLC, "Entertainment Technology Center Named Official Testing Center by Digital Cinema Initiatives," news release, December 1, 2002, Digital Cinema Initiatives, accessed February 16, 2013, http://www.dcimovies.com/press/12-01-02.pdf.

[39] Digital Cinema Initiatives, LLC, "DCI Member Studios Unanimously Approve Pursuit of Delivery System Architecture for Digital Cinema to Accommodate Both 4K and 2K Projectors," news release, November 12, 2003, Digital Cinema Initiatives, accessed February 16, 2013, http://www.dcimovies.com/press/11-12-03.pdf.

[40] For example, SMPTE 428 describes the Digital Cinema Distribution Master (DCDM) and the Digital Cinema Package (DCP); SMPTE 430 describes digital cinema management and operations, including some aspects of encryption; and SMPTE 431 describes digital projection standards (SMPTE 431).

DCI's System Specification has ultimately defined and standardized the system requirements for the creation of digital cinema packages across the industry and throughout the world.

III. The Ins and Outs of Digital Cinema Packages

Understanding a DCP's Component Parts

It is impossible to gain a comprehensive understanding of the risks associated with the long-term preservation of DCPs without possessing a detailed knowledge of a DCP's component parts. However, this task in turn necessitates a thorough understanding of how a set of files becomes conformed to a DCP's specifications, due to the fact that the image, audio, and subtitle files that will ultimately comprise a DCP differ at every stage of the creation process. Recognizing precisely how these files differ can have a significant impact on the choices an institution may make about which of these elements to preserve. In this section I will address some of the principal features that define a DCP vis-à-vis an in-depth explanation of the processes that any set of media files must undergo in order to become a DCP.

Creating DCPs

Digital Source Master

Digital Source Master (DSM)

- *Unencrypted*
- *Image files are unstandardized*
- *Audio files are unstandardized*
- *Timed text and subtitle files may not exist*
- *Color space is unstandardized*

According to the FIAF Technical Commission, "the main intention of the DCP is to serve as a flexible and secure format for delivery and projection of digital movies on a very high quality level."[41] Key to this definition is the word "flexible"—a variety of different elements

[41] Arne Nowak, "Digital Cinema Technologies from the Archive's Perspective," La Fédération Internationale Des Archives Du Film (FIAF), Technical Commission, accessed February 16, 2013,

may be involved in the production process, and therefore a system specification for DCPs must accommodate a wide spectrum of production environments. Therefore, the first stage of creating a DCP centers on a concept known as the Digital Source Master (DSM). The term 'DSM' functions as a catch-all expression that refers to any content coming out of a digital post-production environment that will be eventually converted into a DCP, and which is technically defined as a digital master "from which different versions and duplication masters may be created."[42]

The DSM was specifically designed to remain unstandardized. Rather than describing a specific set of files or components, a DSM is loosely defined to describe the "assembly of the elements of a movie," which "can be made of any color space, resolution, sampling frequency, color component bit depths and many other metrics."[43] It is also important to note that the DSM can be comprised of any file format. Moreover, because there are no minimum standards that describe either a DSM's component parts or that dictate minimum levels of quality, DSMs can be assembled using a wide variety of hardware and software. Although DSMs are frequently assembled in post-production facilities that have access to professional-grade editing, mastering, and special effects software, DSMs also can be assembled using most non-linear editing systems.[44]

A DSM can therefore encompass anything "from a single combined picture and sound source (as basic as a Digital Betacam or an HDCAM tape), to a complex set of separate picture and sound data files."[45] Consequently, there can be great variation among DSMs in terms of quality, content, and file size. It is also important to note that the DSM does not represent the work in its final format because the files have not yet been standardized.

Digital Cinema Distribution Master

Once a DSM has been assembled, it will then be used to create a Digital Cinema Distribution Master (DCDM). A DCDM is tenuously defined in the DCI System Specifications as,

> A collection of data file formats, whose function is to provide an interchange standard for Digital Cinema presentations. It is a representation of images, audio and other information, whose goal is to provide a complete and

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http://www.fiafnet.org/commissions/TC%20docs/Nowak%20-%20Digital%20Cinema%20Technologies%20v2%200%20FIAF-TC_final%20V1%201.pdf.

42 Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 152.

43 Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 25.

44 "DVS Digital Video Systems, AG, "Supplement User Guide: CLIPSTER DCI Mastering," 2008-2010, accessed February 16, 2013, http://www.dvs.de/fileadmin/downloads/products/videosystems/clipster/extraweb/support/documentation/archive/dci/sup_clipster_dci_v2_0.pdf.

45 FIAF Technical Commission, "FIAF Technical Commission Recommendation on the Deposit and Acquisition of D-cinema Elements for Long Term Preservation and Access v. 1.0, 2010-09-02," La Fédération Internationale Des Archives Du Film (FIAF), February 09, 2010, accessed February 16, 2013, http://www.fiafnet.org/pdf/D-Cinema%20deposit%20specifications.pdf.

> standardized way to communicate movies (compositions) between studio, post-production and exhibition.[46]

The last sentence in this description is particularly noteworthy because many critics of the DCI's System Specifications argue that the standards this document outlines are both insufficient and unstable. Upon the initial release of the System Specification in 2005, the National Association of Theatre Owners (NATO) voiced these sentiments by releasing a memo that referred to the DCI's recommendations as, "incomplete and imperfect," and concluded that although the DCI's work may have laid a useful foundation, "work remains to be done."[47]

While the criticisms leveled against the DCI specifications by Fithian and others are not without merit, they take for granted the inherently mutable nature of any digital standard, which will be discussed in greater detail below.

In the seven years since the DCI's initial System Specification was published, two drafts and over 200 additional errata have been subsequently added. In part, the continual revisions to the DCI's System Specification reflect the fact that digital cinema is a rapidly changing field, and that standards are ephemeral with regard to digital formats.[48] But these additions also underscore and lend credence to NATO's observation that the standards are "incomplete." There are many crucial aspects of the System Specification that remain unstandardized, ranging from how DCPs are made to the way servers and projectors are formatted

Digital Cinema Distribution Master (DCDM)

- *Unencrypted*
- *Image files are TIFF Revision 6.0 files*
- *Audio files are uncompressed 24 bit 48kHz or 96kHz Broadcast Wave (.WAV) files*
- *Timed text files are either XML-based documents or a set of Portable Network Graphic (.PNG) images mastered at the same resolution as the image files*
- *Color space is XYZ*

[46] Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 25.
[47] FIAF Technical Commission, "FIAF Technical Commission Recommendation on the Deposit and Acquisition of D-cinema Elements for Long Term Preservation and Access v. 1.0, 2010-09-02," 4.
[48] Howard Besser, "Digital Preservation of Moving Image Material?," *The Moving Image: The Journal of the Association of Moving Image Archivists*, Fall, 1, no. 2 (2001): 46.

The DCDM is the set of master files from which all projection copies of the film will be produced. The DCDM's purpose is threefold: to arrange all of the various components of the DSM (image, audio, and subtitles) into a standardized file structure; to equip all files within the DCDM with metadata that will synchronize all of these tracks together in order to maintain "frame-based lip sync"[49] throughout the presentation; and to format these files according to standards defined in the System Specification.

In order to become a DCDM, the DSM files may be compressed, transcoded, and arranged in a hierarchical image structure to create the standardized set of files that will comprise the DCDM. According to Jim Whittlesey, the Senior Vice President of Technology at Deluxe,

> If the files are delivered in a compressed format (lossily [sic] or loss-less), we must first uncompress the files. If the resolution of the file does fit one of the Digital Cinema containers (for 2K scope 2048x858, for 2K flat 1998x1080, for 4K scope 4906x1716, for 4K flat 3996x2160), then you need to up-res to fill at least one dimension of the above containers.[50]

The DCDM specifies standardized "image containers and colorimetry" for the image components, "bit depth, sample rate, minimum channel count, channel mapping and reference levels" for the audio components, and subtitles and timed text to be encoded as XML-based documents or Portable Network Graphic (.PNG) files respectively.[51]

The DSM picture files that will be used to create the DCDM will usually arrive as a set of sequentially numbered, uncompressed TIFF files, which will likely be in a proprietary RGB color space.[52] The first step will be to transform these images into the DCI-approved XYZ color space. The specified file format for DCDM image files is TIFF Revision 6.0. If the image files do not already conform to this standard upon arrival, then they will be transcoded into TIFFs at this point in time.

The DCI's System Specifications allow for up to 16 audio tracks, which will usually arrive as a series of uncompressed Broadcast Wave (.WAV) files,[53] with one .WAV file per channel per reel.[54] In order to be DCI-compliant the frame rate must be exactly 24.00 or 48.00 fps,[55] however if the audio tracks arrive on broadcast standard tape, its frame rate may be 23.98, 25, or 29.97 frames per second (fps). In this case, the audio will have to undergo a process

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49 Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 26.
50 Jim Whittlesey, "More Questions for Jim Whittlesey," e-mail message to author, May 2, 2013.
51 Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 15 and 36.
52 Peter Wilson, "Introduction to DC Mastering," *The EDCF Guide to Digital Cinema Mastering*, August 2007, accessed February 17, 2013, http://www.edcf.net/edcf_docs/edcf_mastering_guide.pdf, 5.
53 Peter Wilson, "Introduction to DC Mastering," 5.
54 Jim Whittlesey, "Mastering - The Main Process," *The EDCF Guide to Digital Cinema Mastering*, August 2007, 10, accessed March 3, 2013, http://www.edcf.net/edcf_docs/edcf_mastering_guide.pdf.
55 48 fps is only possible for 2K; a 4K file at 48 fps is not permitted.

known as time-stretching, which will adjust the audio files so that they conform to the 24 fps standard.[56] This will prevent the audio files from gradually drifting out of sync.

Additionally, the audio files must be 24 bit and may have a sample rate of either 48kHz or 96kHz.[57] As Richard Welsh of Dolby Laboratories explains, "the principle for these two sample rates is to have a fixed known number of audio samples per picture frame upon replay. This ensures that reel breaks are completely seamless and also allows arbitrary edits to be made"[58]

The subtitle files and timed text files will typically arrive already in an either eXtensible Markup Language (XML) output file, in which case there will be one XML file per reel,[59] or in a series of losslessly compressed .PNG files. In the latter case, each .PNG image will arrive with a corresponding control file that provides information about precisely where, when, and for how long the image should be displayed onscreen.[60] This will allow the .PNG images to be graphically overlaid on top of the image at the correct point in time during the film's playback. It is important to note, however, that the .PNG files must be mastered at the same resolution as the image files that comprise the film, such that a 4K master must have a corresponding set of 4K .PNG files.[61]

The various image, sound, and subtitle files may already be DCI-compliant before the DCDM mastering process begins. However if they are not, the files must be standardized to meet the DCI's System Specifications before they can become a DCP. However the System Specification underscores the fact that on their own, the files comprising the DCDM,

> do not represent a complete presentation. Synchronization tools, asset management tools, metadata, content protection and other information are required for a complete presentation to be understood and played back as it was intended. This is especially important when the files become compressed and/or encrypted and are no longer recognizable as image essence or audio essence in this state.[62]

It is also important to note that a DCDM's content is not encrypted, and may be either uncompressed or losslessly compressed. This typically results in an extremely large file size. As Thomas Christensen, curator at the Danish Film Institute explains, "because of the practical difficulties in handling such a large size of file, DCDMs are typically only created as a virtual entity, a frame at a time, as the intermediate step between the DSM and the DCP.

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[56] Richard Welsh, "Audio Processing," *The EDCF Guide to Digital Cinema Mastering*, August 2007, 13, accessed March 3, 2013, http://www.edcf.net/edcf_docs/edcf_mastering_guide.pdf.
[57] Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 30.
[58] Richard Welsh, "Audio Processing," 13.
[59] Jim Whittlesey, "Mastering - The Main Process," 7.
[60] Mazin Al-Jumaili, "Incorporating Subtitle Files into the Digital Cinema Package," *The EDCF Guide to Digital Cinema Mastering*, August 2007, 19, accessed March 3, 2013, http://www.edcf.net/edcf_docs/edcf_mastering_guide.pdf.
[61] Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 35.
[62] Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 43.

In other words, a complete DCDM of the work might not actually exist."[63] Nicola Mazzanti, deputy director, curator and head of digitization at the Belgian Cinematek, concurs. "[The] DCDM [is] like a mythical object that does not exist anymore because in the workflow of productions, … it's not even produced. It's virtually produced in the machine but then it doesn't exist anymore."[64]

Digital Cinema Package

In order to become a DCP, this set of files, which will be described on a more granular level below, must undergo two additional processes: compression, and packaging. During these processes files may also undergo encryption, which is usually, although not necessarily applied.

Digital Cinema Package (DCP)

- *May be either encrypted or unencrypted*
- *Image files are sequentially numbered, lossy JPEG 2000 files in an MXF wrapper*
- *Audio files are uncompressed 24 bit 48kHz or 96kHz Broadcast Wave (.WAV) files*
- *Timed text files are either XML-based documents or a set of Portable Network Graphic (.PNG) images mastered at the same resolution as the image files*
- *Color space is XYZ*
- *Packing List, Composition Playlist, AssetMap, and VolumeIndex are added*

Compression

The DCI System Specifications state that the audio files and XML document containing subtitling information may remain uncompressed because ultimately these files take up a negligible amount of storage space when compared to the image files. According to the Fraunhofer Institute, an industry leader that manufactures one of the most widely used DCP software systems currently available, the image files require, "huge data storage capacity – one to four terabytes for every hour of action, and this doubles for 3D movies."[65] In order to reduce the DCDM's enormous file size, each TIFF file must be compressed using the JPEG 2000 compression standard. JPEG 2000 compression will be applied to every

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[63] Thomas Christensen, "Legal Deposit of Digital Masters (Case: DFI)" (Guest Lecture, New York University, United States, New York, March 6, 2012).
[64] Nicola Mazzanti, "Interview with Nicola Mazzanti." Telephone interview by author. January 25, 2013.
[65] Fraunhofer-Gesellschaft, "End of the Film Reel," *Fraunhofer Magazine 1.2012*, January 20, 2012, International, accessed February 16, 2013, http://www.fraunhofer.de/en/publications/fraunhofer-magazine/2012/fraunhofer-magazine_1-2012.html.

individual TIFF file, resulting in a .J2C file. This .J2C file will then be sub-divided into individual "reels."

The "reel" is a vestigial concept stemming from the fact that the DCI group was compelled to model their open architecture system for digital cinema on analog film projection. Therefore certain concepts—such as a feature film being split into several reels—must be supported in the System Specifications.[66] The DCI defines the concept of a digital "reel" in loose terms, explaining that, "a reel represents a conceptual period of time having a specific duration chosen by the content provider."[67] Each reel is set up as a distinct folder that contains a set of track files—one for image, one for sound, and one for subtitles or timed text.[68]

The file structure of each reel, which will be explored in the following section, relies upon a standard file naming convention to organize each image file within the reel so that the images may be synchronized to the other content. Although this naming convention is not specified, typically it will include the name of the feature (or an abbreviation thereof), the reel number, and the frame number.[69]

The DCDM is required to contain the metadata necessary for synchronization to occur. Once a reel has been created, the .J2C file for a given reel is wrapped into a single Material eXchange Format (MXF) track file.[70] The track file information tells the equipment in the cinema how to play back the various elements of the complete presentation. Although it will be addressed in greater detail below, the general concept of MXF, notes Wilson, "is that of a file wrapper enclosing both the content and its associated metadata."[71]

Once an MXF track has been created for a given reel, a DCP's creators have the option to encrypt each track file.[72] This process will be addressed at greater length below. Although encryption can also be applied after a DCP has been made, it is typically applied at this stage during the mastering process.

After encryption has been applied to the MXF track files, each reel is placed in order within the "Composition Playlist" (CPL), which is a XML-based list that defines how, when, and in what order the various elements will be played back during a presentation. Ultimately the CPL will consist of, "an ordered sequence of "reels", each referencing an external set of track file(s). These track files could be one or more of the following; a sound, a picture or subtitle track file."[73] An exhibitor or projectionist will ultimately use the CPL to create the

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[66] Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 44.
[67] Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 24.
[68] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 88.
[69] Jim Whittlesey, "Mastering - The Main Process," 10.
[70] Jim Whittlesey, "Mastering - The Main Process," 7.
[71] Peter Wilson, "MXF Primer," The EDCF Guide to Digital Cinema Mastering, August 2007, 20, accessed March 5, 2013, http://www.edcf.net/edcf_docs/edcf_mastering_guide.pdf.
[72] Encryption can also be applied after a DCP has been made, however it is typically applied at this stage during the mastering process.
[73] Jim Whittlesey, "Mastering - The Main Process," 9.

Show Playlist, which will contain all of the necessary components required for the presentation of the film, including trailers, advertisements, relevant subtitles, etc.

Packaging

After the DCDM files have been compressed and encrypted, they must be packaged. A DCP represents a complex group of files whose structure must be maintained in order for the information to be understood and played back as its creators intended. According to the System Specification, "packaging is a way to organize and wrap this material in such a way as to make it suitable for storage and transmission to its destination, where it can be stored and then easily unwrapped for a coherent playback."[74]

In addition to Composition Playlists, there are several items that are must be in the packaging process including a Packing List (PKL), an Asset Map and an optional VolumeIndex. Because they are unique to the format specifications for a DCP, the presence of these assets within a file directory provide the easiest way of identifying a DCP. Their arrangement within a DCP's file directory will be addressed in the following section.

A PKL is an XML document that includes a complete list of all the files within a DCP. This list "contains the identifiers of all assets in the DCP and includes further information regarding the issuer of the package, the system type that was used to create the package, etc. The PKL furthermore contains hash values for each asset in the package."[75] The latter is used by the playback server, which has the capacity to calculate the hash value of every asset file and compare it to the hash value originally listed in the PKL to ensure the integrity of the files.

Both the Asset Map and VolumeIndex are XML documents that describe the asset's location within the DCP. Every file has a Universally Unique Identifier (UUID), and the AssetMap, "contains for each asset an entry that maps the UUID of the asset to a path on a file system."[76] If the creator of a DCP chooses, the assets can be split into chunks by the software used to create the DCP. Typically this would happen if they files were particularly large. If the assets are sub-divided into chunks, then the AssetMap will contain the location of the chunks, and the VolumeIndex will be used to identify the location of the assets.

Encrypting DCPs

To protect a DCP's content, Advanced Encryption Standard (AES) 128-bit encryption is often applied to the MXF track files at this stage so that playing back a DCP will require a unique 'key' to unlock it contents. AES encryption is a free, widely used cipher established by the National Institute of Standards and Technology (NIST) in 2001, which will be discussed in greater depth below.

[74] Digital Cinema Initiatives, LLC, "Digital Cinema System Specification Version 1.2," 43.
[75] Arne Nowak, "Digital Cinema Technologies from the Archive's Perspective," 6.
[76] Arne Nowak, "Digital Cinema Technologies from the Archive's Perspective," 6.

However, in order to ensure the protection of this key, the AES key must itself be encrypted. This is accomplished by using a second, substantially different cryptographic algorithm called RSA, the principal benefit to which is that it provides digital cinema distributors with the ability to generate a new set of keys for every single instance of a DCP's playback. Authorizing each individual screening of a DCP allows distributors to maintain tight control over its content. This is accomplished by issuing a "Key Delivery Message" (KDM), which is a small human-readable XML file that is typically emailed to the exhibitor (or in certain cases, delivered directly to the exhibitor on flash drives), and contains the set of keys necessary to unlock a DCP's content.

KDMs have several restrictive features that are designed to protect a DCP's content from being unlocked for any reason except its intended engagement. Foremost among these is that KDMs are designed to be active only for a short window of time before, during, and after the prescribed showtime. The KDM will remain invalid until this window begins, and will be invalid after this window passes.[77] Finally, KDMs have checksums embedded within them to ensure their authenticity and prevent their manipulation during delivery to the cinema.[78]

Additionally, KDMs are server-projector specific; each KDM is created to work in conjunction with a pre-determined combination of hardware, which the KDM identifies by recognizing a unique digital signature that includes the device's serial number. A KDM will not work if it is connected to devices with unrecognized signatures, and therefore this information must be relayed before a KDM can be issued.

This information is stored within a "Facility List Message" (FLM), which is designed to contain all of the digital certificates for a given theatre that may be used for the playback of a DCP. According to Karagosian, "The FLM should be assembled by the theatre owner's equipment, digitally signed by the equipment, and transmitted by the theatre owner's system to those entities authorized to create KDMs."[79] This ensures that playback of a DCP will not be possible on any device apart from the given projector-servers working in tandem, and also guarantees that the playback devices come from a trusted source.[80]

When a KDM arrives at a theatre, a theatre manager will copy the contents of the KDM to the server's hard disk. When the encrypted DCP arrives it will be connected to the server. When this happens the theatre manager will be prompted to enter the key, which will be applied from the XML document. This will allow the server to "ingest" the DCP by copying its content to its hard disk. During ingest the server checks the DCP for errors using the checksum that was calculated when the DCP was created.[81] Once a DCP has been

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[77] *KDM De-constructed, dir. James Gardiner, perf. James Gardiner, CineTechGeek YouTube Channel, July 15, 2010, accessed May 6, 2013, http://www.youtube.com/watch?v=et-h2Qi2TWA.*

[78] Arne Nowak, "Digital Cinema Technologies from the Archive's Perspective," 8.

[79] Michael Karagosian, "What is a Facility List Message?," Digital Cinema Technology Frequently Asked Questions (FAQs), accessed March 03, 2013, http://www.mkpe.com/digital_cinema/faqs/tech_faqs.php.

[80] Certificates are created and signed by the equipment manufacturer, which serves to trace the provenance of hardware and to ensure that it is a trusted device.

[81] Arne Nowak, "Digital Cinema Technologies from the Archive's Perspective," 13.

successfully ingested, the theatre manager can select the appropriate items[82] from the DCP's file directory to create a playlist for a certain show that is ready to begin as soon as the theatre manager presses 'play.'

File Structure and Component Elements

When all of the above components have been appropriately compressed and packaged, the DCP will be complete. The result will be a file that is required to contain, at bare minimum, a Composition Playlist, an AssetMap, a Packing List, and a single reel of image and/or audio. Below is a screenshot of what a basic file structure looks like.

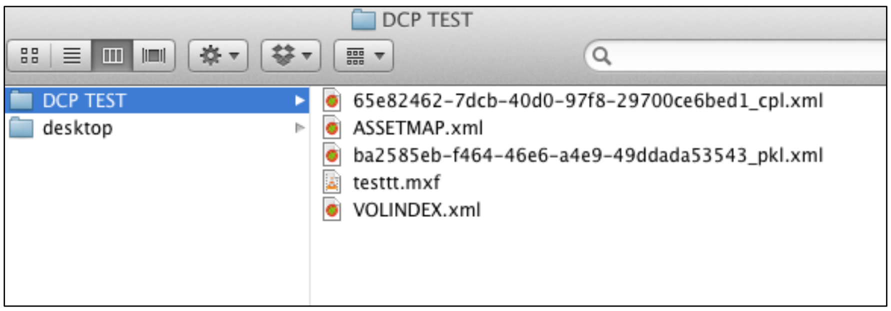
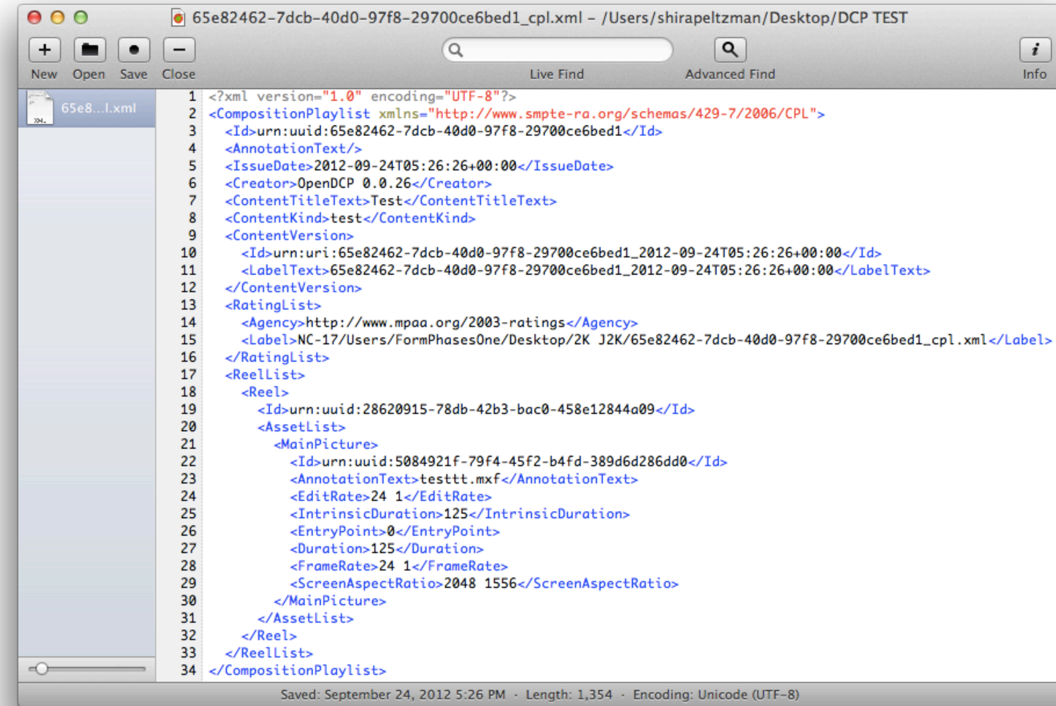


Fig 1. File directory of a DCP

The first file in the file directory is the Composition Playlist (65e82462-7dcb-40d0-97f8-29700ce6bed1_cpl.xml). The CPL, seen below in Figure 2, contains a variety of information about the assets contained within the DCP, among which is the film's MPAA rating (<Label>, line 15).

[82] Most DCPs will contain multiple works, each of which is known as a "Composition Playlist" (CPL). A CPL is defined as a "self-contained representation of a single complete D-Cinema [digital cinema] work, such as a motion picture, or a trailer, or an advertisement, etc." Society of Motion Picture & Television Engineers, SMPTE ST 429-7:2006 § 3, "Digital Cinema Packaging" (Standard).

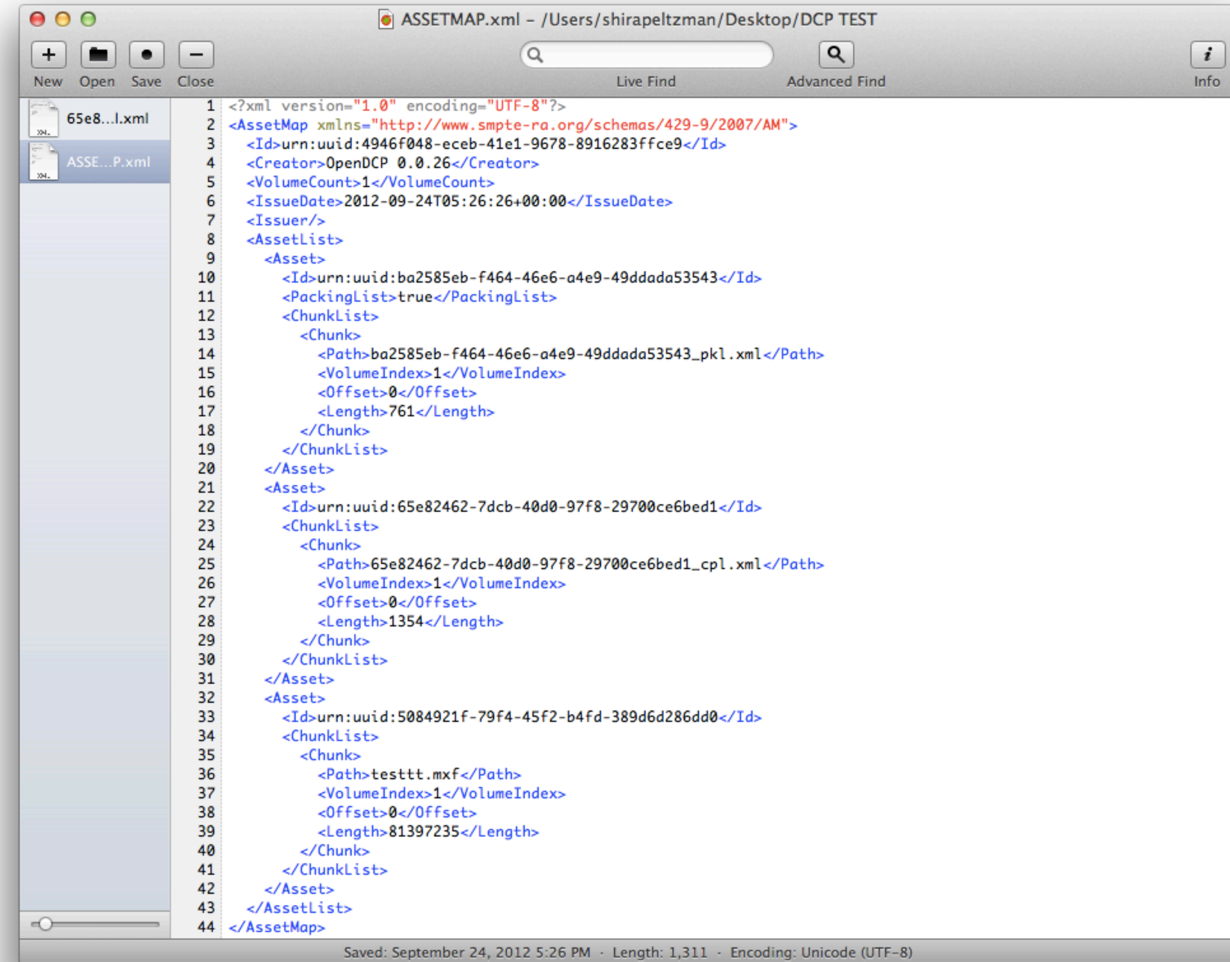



```xml
1  <?xml version="1.0" encoding="UTF-8"?>
2  <CompositionPlaylist xmlns="http://www.smpte-ra.org/schemas/429-7/2006/CPL">
3    <Id>urn:uuid:65e82462-7dcb-40d0-97f8-29700ce6bed1</Id>
4    <AnnotationText/>
5    <IssueDate>2012-09-24T05:26:26+00:00</IssueDate>
6    <Creator>OpenDCP 0.0.26</Creator>
7    <ContentTitleText>Test</ContentTitleText>
8    <ContentKind>test</ContentKind>
9    <ContentVersion>
10     <Id>urn:uri:65e82462-7dcb-40d0-97f8-29700ce6bed1_2012-09-24T05:26:26+00:00</Id>
11     <LabelText>65e82462-7dcb-40d0-97f8-29700ce6bed1_2012-09-24T05:26:26+00:00</LabelText>
12   </ContentVersion>
13   <RatingList>
14     <Agency>http://www.mpaa.org/2003-ratings</Agency>
15     <Label>NC-17/Users/FormPhasesOne/Desktop/2K J2K/65e82462-7dcb-40d0-97f8-29700ce6bed1_cpl.xml</Label>
16   </RatingList>
17   <ReelList>
18     <Reel>
19       <Id>urn:uuid:28620915-78db-42b3-bac0-458e12844a09</Id>
20       <AssetList>
21         <MainPicture>
22           <Id>urn:uuid:5084921f-79f4-45f2-b4fd-389d6d286dd0</Id>
23           <AnnotationText>testtt.mxf</AnnotationText>
24           <EditRate>24 1</EditRate>
25           <IntrinsicDuration>125</IntrinsicDuration>
26           <EntryPoint>0</EntryPoint>
27           <Duration>125</Duration>
28           <FrameRate>24 1</FrameRate>
29           <ScreenAspectRatio>2048 1556</ScreenAspectRatio>
30         </MainPicture>
31       </AssetList>
32     </Reel>
33   </ReelList>
34 </CompositionPlaylist>
```

Fig 2. Composition Playlist

Inside the CPL there will be a reel list (<ReelList>, lines 17-33) that will contain the UUID (<ID>, line 22) of every reel. The reel's duration is expressed (<Duration>, line 27) in frames, and is measured from the film's entry point (<EntryPoint>, line 26) to the number of frames beyond the film's entry point indicated in the reel's duration. For the above file, the reel begins at frame '0' and lasts for 125 frames. Therefore, the entry point for the above reel is expressed as '0' to indicate the 0 frame, and the exit point, albeit not expressed, is indicated to be the 125th frame following the entry point (the 125th frame in this case). If the above DCP consisted of multiple reels, they would be listed in numerical order, with the information about the second reel beginning on line 33.

The next file in the directory is the AssetMap (ASSETMAP.xml), the content of which is seen below.




```xml
1 <?xml version="1.0" encoding="UTF-8"?>
2 <AssetMap xmlns="http://www.smpte-ra.org/schemas/429-9/2007/AM">
3   <Id>urn:uuid:4946f048-eceb-41e1-9678-8916283ffce9</Id>
4   <Creator>OpenDCP 0.0.26</Creator>
5   <VolumeCount>1</VolumeCount>
6   <IssueDate>2012-09-24T05:26:26+00:00</IssueDate>
7   <Issuer/>
8   <AssetList>
9     <Asset>
10      <Id>urn:uuid:ba2585eb-f464-46e6-a4e9-49ddada53543</Id>
11      <PackingList>true</PackingList>
12      <ChunkList>
13        <Chunk>
14          <Path>ba2585eb-f464-46e6-a4e9-49ddada53543_pkl.xml</Path>
15          <VolumeIndex>1</VolumeIndex>
16          <Offset>0</Offset>
17          <Length>761</Length>
18        </Chunk>
19      </ChunkList>
20    </Asset>
21    <Asset>
22      <Id>urn:uuid:65e82462-7dcb-40d0-97f8-29700ce6bed1</Id>
23      <ChunkList>
24        <Chunk>
25          <Path>65e82462-7dcb-40d0-97f8-29700ce6bed1_cpl.xml</Path>
26          <VolumeIndex>1</VolumeIndex>
27          <Offset>0</Offset>
28          <Length>1354</Length>
29        </Chunk>
30      </ChunkList>
31    </Asset>
32    <Asset>
33      <Id>urn:uuid:5084921f-79f4-45f2-b4fd-389d6d286dd0</Id>
34      <ChunkList>
35        <Chunk>
36          <Path>testtt.mxf</Path>
37          <VolumeIndex>1</VolumeIndex>
38          <Offset>0</Offset>
39          <Length>81397235</Length>
40        </Chunk>
41      </ChunkList>
42    </Asset>
43  </AssetList>
44 </AssetMap>
```

Fig 3. AssetMap

In this case, the reel has been sub-divided into three distinct chunks (lines 9-20; 21-31; and 32-42), each of which has their own UUID (<ID>, lines 10, 22, and 33). The file path of each chunk referenced within the Packing List is listed in the <Path> field (lines 14, 25, and 36).

Although a VolumeIndex will not necessarily be included in a DCP, in this case it is because OpenDCP, the software used to create the DCP in this example (listed in the <Creator> fields of the CPL [line 6] and the AssetMap [line 4] respectively) split the asset into chunks. As explained in the previous section of this paper, if the assets are sub-divided into chunks then the AssetMap will contain the location of the chunks and the VolumeIndex will be used to identify the location of the assets. The VolumeIndex (VOLINDEX.xml) is the last file listed in the file directory, and its content can be seen below.

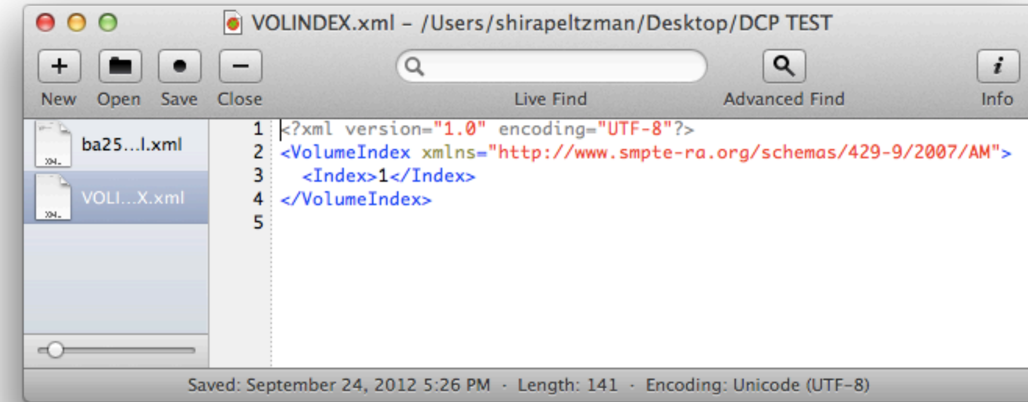


Fig 4. Volume Index

The Volume Index is the only XML file that is not required. In this case, because there is only a single asset in the Asset Map, the Volume Index remains empty.

Also included in the file directory is the Packing List (ba2585eb-f464-46e6-a4e9-49ddada53543_pkl.xml). Below are the contents of the Packing List.

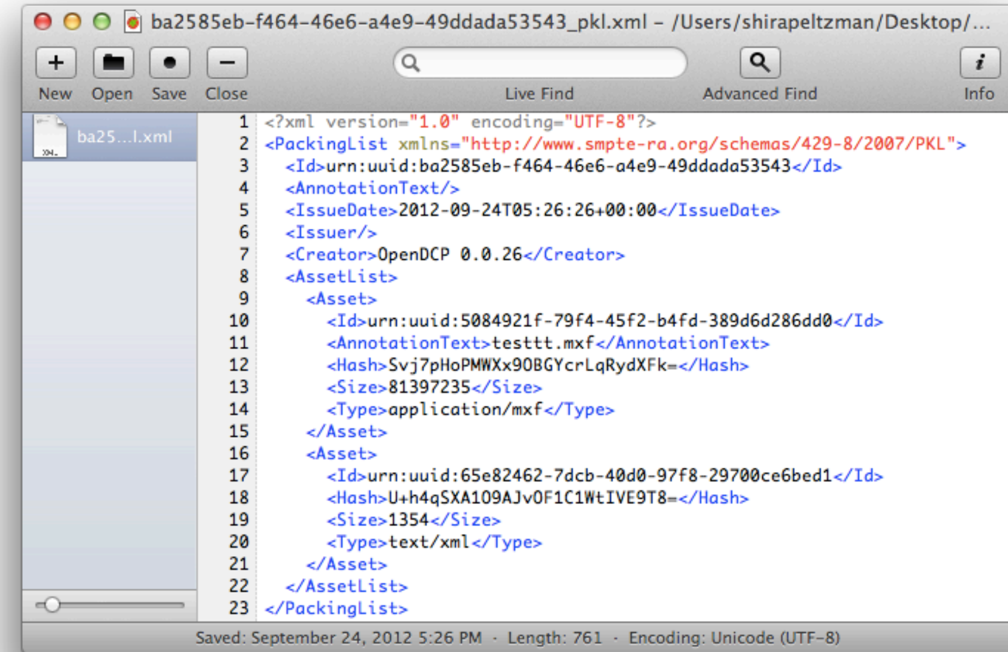


Fig 5. Packing List

The Packing List begins by listing its own UUID (<Id>, line 3), followed by the date of its creation (<IssueDate>, line 5) and the software used to create it (<Creator>, line 7). The Packing List then contains an Asset List with information about the track file that comprises a reel, and the Composition Playlist. The former is identified by the <AnnotationText> field, which lists the reel's file name (testtt.mxf). Typically the reels would all conform to a standard naming convention as described in the above section, however in this case the reels do not. Unlike the CPL and AssetMap whose UUIDs are expressed in their file name, the reel's UUID (5084921f-79f4-45f2-b4fd-389d6d286dd0), revealed in line 10 in the <Id> field, is not.

Some of the PKL's most significant components are the checksums, or hash values, it contains, which are assigned to the assets upon their creation. The server uses these hash values before the film's playback in order to ensure that the files have not been changed. Each asset has its own hash value, which is expressed in the <Hash> field in lines 12 and 18. Additionally, fields expressing each asset's size, expressed in bytes, and format are listed in the <Size> and <Type> fields respectively (lines 13-14 and 19-20).

The final asset in the DCP's file directory is the reel itself, which is rich in embedded metadata that may prove a useful source of information for archivists. Among this metadata is the track's wrapper, its wrapper's operational pattern, size, duration, overall bit rate, the date it was encoded, and the software that was used to encode the file.

IV. The Growth of Digital Cinema Exhibition Since 1999

The arrival of DCPs in audiovisual archives did not happen overnight. DCPs did not begin to appear in collections until several years ago, nearly half a decade after the advent of digital cinema projection. This section will examine the history and growth of digital cinema exhibition over the past 14 years to address the address why this format did not appear in archives sooner. An exploration of the exhibition landscape over these years will both make clear the challenges that this format faced, and will provide a backdrop for the subsequent discussion of the presence of DCPs in archives around the world.

Advancements in Digital Cinema Projection Technology

A necessary pre-condition for the advent of DCPs was a projector that would be capable of transforming the digital image data contained in a DCP into an image that, when projected onscreen, would roughly approximate that which could be produced on standard 35mm equipment. The 1990s saw significant advances in digital projection technology, and by the decade's close there were two systems—the Liquid Crystal Light Valve invented by the Hughes Aircraft Corporation (but quickly thereafter acquired by JVC), and Texas Instrument's Digital Light Processing (DLP) technology—that were capable of accomplishing this task.

Competing Technology

Though originally shot on film, George Lucas' *Star Wars Episode I: The Phantom Menace* made history in June 1999 by becoming the first theatrically released film to take advantage of these technologies. *The Phantom Menace* was projected digitally on four screens in total, two each in New Jersey and Los Angeles. In addition to garnering press for Lucas' film, the screenings served as a field trial for both Liquid Crystal Light Valve and DLP projectors that would help determine whether one technology offered significant benefits over the other.

To perform this experiment, two of the screens showing *The Phantom Menace* digitally were outfitted with projectors that used the Liquid Crystal Light Valve system, while the remaining screens used DLP projectors. According to Bordwell, the screenings served, "as a shootout between the two systems,"[83] with the DLP projectors ultimately proving to be the decisive victors.

[83] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 42.

Resistance from Exhibitors

The digital release of *The Phantom Menace* was met with significant excitement both within and outside the film industry, and served as a milestone in the history of digital cinema at large. However in spite of the success of these screenings, exhibitors were in no rush to convert their screens to digital. In fact, once exhibiting films digitally became a possibility in the early 2000s, exhibitors were almost uniformly resistant to making the changeover. This is for three reasons.

First, although many within the industry had embraced the first generation of High Definition progressive digital video cameras upon their initial release in the early 2000s, even those who championed this technology were not prepared to argue that the images they produced were commensurate with standard 35mm film. While a vocal minority of key directors and cinematographers praised the new technology and immediately began integrating digital cameras into their productions, no amount of proselytizing could sway the majority of industry leaders who pledged their allegiance to celluloid until digital camera technology improved.

Additionally, as David Bordwell observes, exhibitors "[have] the most to lose" by gambling on new technologies," and consequently, Bordwell observes that "historically, exhibition has been the most conservative wing of the film industry."[84] Theatre owners were disinclined to install digital projectors to accommodate digital cinema before it was ubiquitous.

Finally, the lack of standards for digital cinema exhibition gave theatre owners a further disincentive to install digital projectors. As mentioned above, in the early 2000s there was a wide variety of competing technology for digital cinema exhibition, and theatre owners were reluctant to commit to a product that might be discontinued or superseded within a few years. However even after DCPs became standardized in 2006, most exhibitors still refused to make the changeover due to the high cost of digital projectors, the cost of which to install could be between $50,000 and $150,000 per screen.

Five years after *The Phantom Menace* had made its digital debut, just over 100 screens in the U.S. had screens equipped for digital projection. As a result of exhibitors' refusal to convert, even productions that had gone through digital shooting and post-production processes would still have to be output to film for its theatrical release in most locations. This guarantee of 35mm prints even for digitally shot titles took the pressure off theatres to convert, and helped keep the rate of conversion to digital exhibition extremely low throughout the first half of the 2000s.

3D

For those with major stakes—creative or financial—in digital cinema, it became imperative to find a tool that would force theatres to make the conversion. The solution to this

[84] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 8 and 76.

problem came in early 2005 when several of the biggest name Hollywood directors, including George Lucas, James Cameron, Robert Zemeckis, Robert Rodriguez and Peter Jackson, initiated a plan to convince theatre owners that making the investment in digital projection would prove to be worth their while. Mounting a vigorous campaign to promote digital cinema that was built around their commitment to 3D technology, which would require digital projection, these directors helped kick-start the process of conversion, which began to quicken noticeably.

As Bordwell observes, it would be foolhardy to attribute the steady growth of digital cinema after 2005 to these directors alone.[85] In reality it was a confluence of events that occurred circa 2005 and 2006, including the appearance of standards, improvements in digital projector technology, and the advent of the Virtual Print Fee (VPF)[86] program to help theatres afford conversion, in addition to the endorsement of 3D technology by these directors that ultimately enabled a conversion to digital en masse. However the affect of the directors' campaign for 3D cannot be underestimated. Bordwell puts it bluntly: "3D, as we now know, was the Trojan Horse that gave exhibitors a rationale to convert to digital."[87]

In 2006 approximately 1,500 screens, or just over two percent of U.S. screens, were digital. Over the next several years, 3D films became a regular fixture at the box office. Although the theatres that had converted to digital early on began to reap modest rewards from these releases, the rate of conversion remained sluggish. By 2008 only 5,000 screens, or roughly eight percent of screens in the U.S., had converted.

The Tipping Point

The incentive that finally justified a widespread conversion was the release of James Cameron's long-awaited science fiction epic *Avatar*. The film's 3D technology was promoted heavily in marketing campaigns and theatres scrambled to convert in time for the film's December 2009 release date. The anticipation that surrounded *Avatar* successfully jump-started the process of conversion. As a result, "a doubling of digital projector installations took place, resulting in more than 16,000 digital cinema systems installed worldwide,"[88] and pushing the number of digital screens in the U.S. past the 10,000 screen milestone.

Avatar helped create a critical mass for conversion to digital because the enormous box office that the film generated, which was due in part to its 3D technology, convinced many theatre owners that conversion would be profitable. By 2011 over half of the world's

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[85] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 67.

[86] A Virtual Print Fee is a subsidy paid by distributors toward a theatre's purchase of a digital cinema projector. Theatres wishing to convert must enroll with a third party middleman known as an "integrator," who will install and maintain the digital projector up front. The integrator will then charge the distributor a Virtual Print Fee for each screening, and over time the fees will pay off the projector, allowing theatres to own the equipment outright.

[87] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 194.

[88] Michael Karagosian, "Digital Cinema in 2010 - A Mid-Year Report," MKPE: Publications, 2010, accessed April 08, 2013, http://mkpe.com/publications/d-cinema/reports/June2010_report.php.

cinema screens had been converted,[89] and by March of the following year "two-thirds of U.S. screens had gone digital," with screens converting "at a rate of twenty each day."[90]

Picking Up the Pieces

However the changeover to digital has not been easy on exhibitors. The high cost of installing digital projectors has made it impossible for many smaller and independent theatres to consider conversion, putting these theatres in a precarious position. The National Association of Theatre Owners recently estimated that, as a result of their inability to afford converting to digital, "up to 20% of theaters in North America, representing up to 10,000 screens, would not convert and would probably close."[91]

But despite these predications, the number of screens converting to digital has continued to rise. As of January 2013 almost 70% of screens have been converted globally, (up from over 50% in 2011)[92] with the percentage of digital screens in the U.S. being even higher. According to John Fithian, the head of NATO, today "32,000 of the total screens in the US"—or just over 80%—"are now digitized."[93,94] In spite of the holdouts, the numbers make it clear that the digital tide has already turned.

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89 David Hancock, "D-Cinema Takes the Lead," Screen Digest, May 8, 2012, Executive Summary, accessed April 8, 2013, http://www.screendigest.com/reports/201248a/2012_05_d-cinema_takes_the_lead/view.html.

90 David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 79.

91 Michael Hurley, "We're About to Lose 1,000 Small Theaters That Can't Convert to Digital. Does It Matter?," Indiewire, February 23, 2012, accessed April 08, 2013, http://www.indiewire.com/article/were-about-to-lose-1-000-small-theaters-that-cant-convert-to-digital-does-it-matter.

92 Charlotte Jones, "Over 69 per Cent of World Screens Now Upgraded to Digital Cinema in 2012," Screen Digest, January 14, 2013, accessed April 08, 2013, http://www.screendigest.com/news/2013_01_over_69_per_cent_of_world_screens_now_upgraded_to_digital_cinema_in_2012/view.html.

93 It is important to note that not every theatre or screening space in the U.S. is a member of NATO, and therefore Fithian's claim that the NATO figures represent the totality of screens in the U.S. should be regarded as misleading and inaccurate. While the number of screens unaffiliated with NATO is difficult (if not impossible) to measure, it is accurate to state that NATO screens, which include the three major circuits of U.S. film theatres—American Multi-Cinemas, Cinemark, and Regal Entertainment—do represent the vast majority of screens in the U.S. Therefore Fithian's statement, albeit not wholly precise, remains an acceptable measure the percent of U.S. screens that have converted to digital.

94 Ty Burr, "Digital Projection Threatens Some Community Theatres," Boston Globe: Movies, January 27, 2013, Arts, accessed April 08, 2013, http://www.bostonglobe.com/arts/movies/2013/01/27/digital-format-brings-closure-small-town-movie-theaters/MGVHWeNISBWp02Wc8wbhLL/story.html.

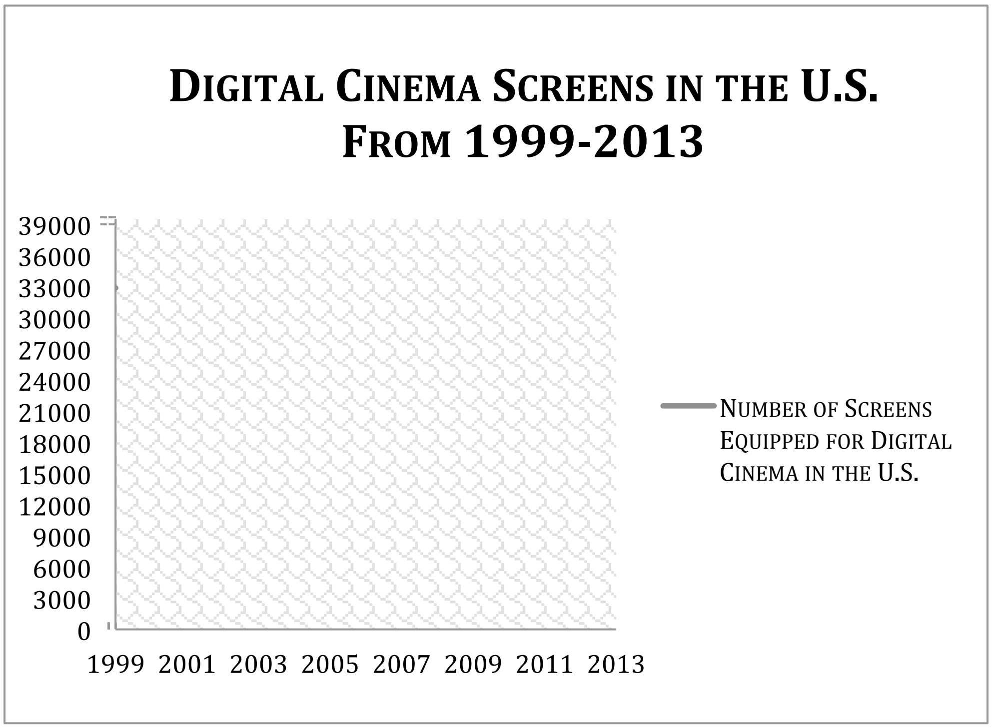

Figure 1. *Growth of Digital Cinema Screens in the United States* (2013)

V. The Presence of DCPs in Archives Around the World

Status Quo

It took more than 10 years for a wholesale adoption of digital cinema to take place. During this time some DCPs were being exhibited, but for the most part other, more familiar exhibition formats, including standard 35mm film, HD-CAM, and Digital Betacam, predominated. Consequently, the status quo remained unaffected on the whole, and the relative scarcity of DCPs led to the format being largely absent from the collections of most film archives and audiovisual institutions. The lack of DCPs within these collections allowed institutions to postpone addressing this format and its attendant preservation concerns, leading to the adoption of what can best be described as an 'out of sight, out of mind' approach to the format during the first half of the 2000s.

However after the pace of conversion to digital cinema exhibition started to accelerate around 2006, DCPs gradually became more commonplace as an exhibition format, and began to arrive at audiovisual institutions around 2008 or 2009. As DCPs increased in popularity toward the end of the decade, the growing presence of DCPs within these institutions created a need for archival workflows and policies surrounding the acquisition and ingestion of DCPs and the development of a viable plan for long-term viability of this format.

Making the Transition

DCPs represent a unique set of challenges even for those institutions that have a robust digital preservation plan already in place. In order to gain an understanding of how audiovisual institutions are adjusting to this format, I have spoken to the curators, conservators, film archivists, or directors of fourteen audiovisual institutions worldwide. These include the Danish Film Institute, the Library of Congress, the Belgian Cinematek, the EYE Film Institute in the Netherlands, the Swedish Film Institute, the Austrian Film Museum, the Asian Film Archive in Singapore, the Cineteca Nacional de México, the National Film Archive of Thailand, the British Film Institute, the National Film and Sound Archive of Australia, the George Eastman House, the Academy Film Archive, and the Museum of Modern Art in New York.

I conducted these interviews in order to gather a sampling of information about the presence of DCPs within archives around the world, and to better understand whether and how these institutions have integrated this format into their collections. Nine of these institutions have already begun accepting DCPs and have either developed archival workflows for this format or were in the process of doing so when we spoke. These are the Danish Film Institute the Belgian Cinematek, the EYE Film Institute in the Netherlands, the Cineteca Nacional de México, the British Film Institute, the National Film and Sound Archive of Australia, the Academy Film Archive and the Museum of Modern Art in New York.

The remaining five institutions report that they have not yet begun accepting DCPs. These include the Austrian Film Museum, the Asian Film Archive, the National Film Archive of Thailand, the George Eastman House, and the Library of Congress. Nevertheless, in spite of this fact several of these institutions report that they have already begun to plan for their arrival. For example, both the George Eastman House and the Library of Congress have already begun drafting policies and workflows surrounding the acquisition and ingestion of DCPs that will fit into their existing digital preservation infrastructure.

In this regard the Library of Congress is particularly well advanced. They have a robust digital preservation plan in place and have already determined what the technical workflow for ingesting a DCP's content into its digital repository will be. The only part of this process that remains to be determined is the fact that, as Mike Mashon, Head of the Moving Image Section at the Library of Congress, points out,

> The copyright office is in D.C. on the fourth floor of the James Madison building and we're here in Culpeper, Virginia seventy miles away. What typically happens when a 35mm film or videotape arrives at the copyright office is that they can look at it to verify the registration is what it says it is. They can look at the leader of the film to figure that out. With a DCP, the way it's going to have to work is that the DCP will have to come here [to Culpeper, Virginia] we will have to read it in some fashion, and then verify with the copyright office that it is indeed what it says it is. And we haven't quite worked that out yet.[95]

Although it is a significant detail, the challenge Mashon describes is by no means insurmountable. The Library of Congress has already laid the essential groundwork for ingesting DCPs, and solving this problem will bring them one step closer to being able to acquire DCPs in earnest. Given the format's steadily increasing ubiquity, this is likely to happen sometime in the near future.

Acquiring DCPs

Most European institutions that currently accept the format began receiving their first DCPs approximately five years ago. Developing workflows for DCPs has been a more pressing concern for European countries for two reasons, the most significant being that some European countries like Belgium and Denmark have either already made the transition to becoming completely digital or are on the cusp of doing so. Therefore, it is increasingly likely that DCPs will be the only format that institutions like the Belgian Cinematek and the Danish Film Institute will receive in the future.

However another factor necessitating a workflow for DCPs is that a large percentage of European film productions receive governmental support. The funding almost always comes with strings attached that compel filmmakers to deposit an archival master at the national film archive for long-term preservation. Anne Gant, Head of Restoration, Digital Film and Digital Presentation at the EYE Film Institute, explains how this works in the Netherlands:

> We have a legal deposit agreement in the Netherlands for any films which receive national funding (Filmfonds). This means that if a film receives Filmfonds money (and many of the films produced in [the Netherlands] do),

[95] Mike Mashon and Paul Klamer, "Interview with Mike Mashon and Paul Klamer," telephone interview by author, February 12, 2013.

> then an archival master must be deposited with EYE before the filmmaker receives their final payment from the Filmfonds.[96]

Two thirds of the institutions currently accepting DCPs with whom I was able to speak are located in countries that are affected by these contractual stipulations or by other legal deposit laws. They include Belgium, Denmark, Britain, Sweden, the Netherlands, and Australia.

A major benefit of laws or stipulations that mandate the deposit of archival materials is that they allow archives to avoid negotiations with filmmakers surrounding encryption. According to Thomas Christensen, Curator of the Danish Film Institute, "For Danish cinema we are able to forego encryption, since the legal deposit legislation serves us well, and because virtually all films are subsidized by DFI."[97]

Differing Preservation Plans

Legal or contractual deposit laws have helped to create an impetus for developing long-term preservation plans for DCPs. However, while many institutions have developed these plans, they often differ form one another in fundamental ways. As my interviews make clear, there is currently no consensus among the institutions with whom I have spoken about preserving DCPs and their associated elements in the long-term. Rather, the institutions acquiring this format have wildly varying methods of approaching this task that depend largely on their mission. While the preservation plans tend to share some areas of overlap—most noticeably surrounding how the DCP's content is stored over the long-term—they differ quite significantly in other respects.

Preferred Elements for Acquisition

When an archive acquires a film, it will rarely accept the work in the file format or version of the filmmaker's choice. Rather, each institution typically has a set of guidelines governing the versions and formats that are permissible for submission. This document commonly indicates the institution's preference for receiving a particular version or format of the film, and these are referred to as 'preferred elements'. In many cases institutions document and publish their preferred elements openly online, while others relay this information to filmmakers directly prior to acquiring their work.

Acquiring certain elements over others not only helps streamline the preservation process, in the case of DCPs where every element (ie, the DSM, DCDM, or DCP) has a distinct set of characteristics, allows preservationists to select the set of elements that best fits with its approach to preservation and access. Perhaps the most significant area of divergence between the preservation plans that were related to me for this project can be seen in variety of preferred elements collected by each institution. There is a dramatic range of

[96] Anne Gant, "Re: DCP Introduction," e-mail message to author, February 4, 2013.
[97] Thomas Christensen, "Interview," e-mail message to author, January 21, 2013.

elements preferred across all of the institutions currently accepting or soon-to-be accepting DCPs. For instance, while MoMA prefers the DSM, the Library of Congress, the George Eastman House, the Swedish Film Institute, the Danish Film Institute, the British Film Institute, and the National Film and Sound Archive of Australia have all developed plans that rely on the DCDM as the preferred element for deposit. Meanwhile, the EYE Film Institute prefers color-corrected, uncompressed DPX or TIFF files and a WAV mix, the Cineteca Nacional de México prefers HD-CAM, and the Belgian Cinematek prefers the DCP (although they will also accept a DCDM if one has been produced).

The principal reason for this variance has to do with the fact that every institution has a distinct mission, which in will influence the elements that the curators, conservators, or preservationists prefer for long-term preservation. For example, MoMA's preference for the DSM is logical given that MoMA is a fine art museum. For MoMA, issues surrounding provenance and originality take precedence over concerns about a file's size or format. According to Peter Oleksik, Assistant Media Conservator at The Museum of Modern Art,

> The mandate to preserve and document contemporary art in the "highest order" informs all of the museum's conservation policies, especially as we develop acquisition and preservation plans for born digital material. To properly document and preserve born-digital cinema, the museum is seeking the acquisition of elements that are as close as possible to the original master. In the DCI workflow, this is known as the Digital Source Master (DSM) and is the packaged elements of the work before it goes through the normalization process to derive DCPs. It was agreed on that this would be closest to the artist's original master elements, thus preserving the artist's intent and vision, and allow for the most robust information possible for the future migration and care of this digital material.[98]

But whereas this approach is appropriate for a conservation setting within a fine art museum, it may not make sense for institutions that do not share MoMA's concerns about originality. Nicola Mazzanti believes that it is his responsibility to preserve the way a film looked at the time of its release. He does not prefer the DSM as an archival element because he feels that DSMs do not necessarily reflect how a film actually looked to audiences.

> My problem with a DSM is that I don't know what it is because there are no standardized rules by which I can go from a DSM to a DCP. So if I have a DSM—let's say an HDCAM-SR tape—I have no clue whatsoever how [it looked as] a DCP. … The relationship between the HDCAM—that is the DSM—and the DCP of the same film, is sometimes very loose.[99]

Therefore, the Belgian Cinematek prefers the DCDM (if produced) and the DCP, because the DCP will provide a more accurate record of what audiences saw at the time of a film's release.

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[98] Peter Oleksik, "DSMs vs. DCDMs In the Context of MoMA's Mission," e-mail message to author, May 6, 2013.
[99] "Nicola Mazzanti, "Interview with Nicola Mazzanti."

Moreover, for archives like the Library of Congress that are concerned with preserving an accurate record of how a film was distributed to audiences at the time of its release, the DSM is not a logical choice because it likely won't include subtitle and timed text tracks, and therefore doesn't represent the work in its complete form. As a result, the Library of Congress is in the process of drafting a Best Edition statement for motion pictures that will include DCDMs and DCPs, but will not include DSMs.[100]

Ingesting DCPs

Other areas where these plans diverge include whether the DCPs are checked in real-time upon arrival or merely spot-checked; whether the original hard drives upon which they are received are kept or discarded; and whether and how these files are ultimately re-packaged for long-term storage. As I will explain shortly, all of these actions will have a direct impact on the long-term viability of these files, and the fact that no two institutions have come to the same conclusions about how to deal with this material highlights the amount of work that remains to be done. Among the most important steps that could be taken in this vein would be the development of a set of industry-wide best practices that would provide guidelines for the long-term preservation of DCPs. While every institution will approach the preservation of DCPs slightly differently due to their differing infrastructures, resources, and choices to acquire distinct sets of preferred elements, there are many aspects of preserving DCPs that should not differ from one organization to the next. Developing as a community a set of best practices that institutions could follow regardless of their particular circumstances would be hugely beneficial, and is an important place to start.

Long-Term Storage

Although policies differ across institutions regarding the process through which they ingest DCPs into their digital repository, almost all institutions that I spoke with store DCPs in a similar fashion once they have been ingested. In almost every case, after the DCP has been quality checked two copies of the file are made, resulting in two parallel preservation elements. The file from which the duplicates were made is stored in a secure storage environment, and the redundant preservation files will be output to robotic data tape storage libraries in which the fixity of all elements can be monitored.

However, this storage set-up represents what Christensen describes as, "a single line digital preservation setup." Christensen continues, explaining that,

> To have proper digital preservation a double line preservation setup with redundancy is required. DFI is currently seeking funding to establish such a setup. A proper digital preservation repository with redundancy requires

[100] Mike Mashon and Paul Klamer, "Interview with Mike Mashon and Paul Klamer."

> two different file types stored on two different media in two different geographical locations (at least 100 km/miles apart).[101]

“The biggest challenge,” Christensen concludes, “is the establishment of a robust digital repository.”[102]

VI. Risks

Risks Associated with DCPs

Risks to the long-term preservation of DCPs falls into two categories: those carried by various components of DCPs that may be considered inherent to the format, and those that are posed by challenges surrounding digital preservation more broadly, and that may threaten the long-term survival of a DCP’s content but that are not unique to DCPs. In this section I will evaluate all the challenges to a DCP’s long-term preservation that I have been able to identify, beginning with shared risks and ending with those that only affect DCPs.

JPEG 2000 Format

JPEG 2000 is a wavelet-based compression standard that was created by the Joint Photographic Experts Group (JPEG) committee in 2000. There are several advantages to the format, including a compression architecture that can accommodate either lossy or lossless compression, increased error resilience, and a code stream that is scalable in nature. The latter benefit is made possible by the code stream organization of JPEG 2000 files, which occurs progressively according to “pixel accuracy.” Code streams that are organized this way allows viewers to see a low-resolution iteration of a JPEG 2000 file instantly, and continue to “improve the quality of decoded imagery as more data is received.”[103]

Lossy Compression

However in spite of these benefits, there are also several downsides associated with this format that ultimately translate into a potential risk with regard to DCPs given their use of the JPEG 2000 format. Although JPEG 2000 compression standard allows for either lossy or lossless compression, because the System Specifications caps the bit rate at 250 Mbps, all DCPs that are encoded to be DCI-compliant will have inherently lossy compression.[104] Best

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[101] Thomas Christensen, “Interview.”
[102] Thomas Christensen, “Interview.”
[103] David S. Taubman and Michael W. Marcellin, *JPEG2000: Image Compression Fundamentals, Standards, and Practice* (Boston: Kluwer Academic Publishers, 2002), 402.
[104] Matthew Addis, “Re: Use of JPEG2000 for preservation,” AMIA-Listserv, October 14, 2010, accessed March 4, 2013, http://lsv.uky.edu/scripts/wa.exe?A2=ind1010&L=AMIA-L&P=R30079&I=-3.

practices for long-term preservation universally favor lossless compression, making the lossy DCI standard inadequate—or at the very least not ideal—for preservation. Provided that the film has not been born with lossy compression, it should not be preserved this way.

Interoperability Concerns

Also of importance are problems surrounding the interoperability of JPEG 2000 files as a result of its broadly defined encoding parameters. As Matthew Addis explains, with large and complex standards like JPEG 2000, problems with file interoperability may arise when vendors unintentionally implement differing interpretations of the same standard:

> Both vendors will claim that they support the same standard, but in practice there are problems moving files from one system to another. The problem from a preservation perspective is storing something encoded by vendor A and then finding in the future that only vendor B is still around.[105]

A good example of this comes from Danny Dawson, Production Manager and head of Preservation & Technical Services at the National Film and Sound Archive in Australia. Dawson illustrates how the "different flavors" of JPEG 2000 can create problems with interoperability.

> For us, the interoperability issue is that, for example, Trevor [Carter, who works in the Motion Pictures Laboratory] can't play one of the JPEG 2000 files that we've created down the video end [of the NFSA using OpenDCP] through his kit, and vice versa; we can't play what he's created or ingested [using EasyDCP] down his end of the building.[106]

In a recent discussion on the Association of Moving Image Archivists listserv that touched upon this subject, industry consultant Jim Lindner raised the possibility that although the issue of interoperability is clearly problematic with regard to JPEG 2000, the problem should not be interpreted as a failing of the format itself.

> If a specific system actually captures certain information, but someone else's system does not play it out because they don't happen to think the feature is important - is that a Codec problem? I don't think so. Manufacturers are free to do their own implementations and they make all sorts of decisions based on their own expertise, resources, and the focus of their product and what they are trying to do.[107]

Lindner's observation is valid. His assertion that manufacturers have every right (and often good reason) to use differing implementations of the same standard is important because it

[105] Matthew Addis, "Re: Use of JPEG2000 for preservation."
[106] Danny Dawson, "Interview with Danny Dawson," telephone interview by author, April 18, 2013.
[107] Jim Lindner, "Re: Research Suupporting Jpeg2000 True Mathematical Lossless Compression," e-mail to AMIA-L Listserv, April 11, 2013.

helps to identify and contextualize the root of most interoperability concerns. Nevertheless, whether these issues should be considered a problem inherent to the format or as a result of the fact that manufacturers will—and should—be free to create tools that will implement the standard differently, as Lindner suggests, is ultimately less important in the context of this discussion than the fact that interoperability issues persist with JPEG 2000 files. The fact remains that this problem continues to exist with regard to JPEG 2000 files, and must be addressed as a preservation concern germane to the standard.

Unwieldiness

Additionally, the JPEG 2000 format is unwieldy. Instant playback of or access to JPEG 2000 files is impossible because in order to be viewed or edited, the JPEG 2000 codestream must first be transcoded to another format. However decoding and transcoding a JPEG 2000 codestream are "slow and CPU-intensive"[108] tasks, making this process time-consuming and inefficient. Not only does the extra step require additional resources, more significantly, it provides a disincentive for software engineers to write programs that support the JPEG 2000 standard.

Based on Moore's Law, which is the observation that the processing power of microchips will double approximately every 18 months, the cost of both computer storage and processing power will decrease as the number of components per circuit rises.[109] Therefore, it is possible that the format's large file size will become a lesser challenge in the future because decoding and transcoding a JPEG 2000 file will be a fast, perhaps even seamless task. However as of 2013 this has not yet come to pass, and JPEG 2000 remains a cumbersome format.

Limited Adoption

While a drawback in and of itself, the inconvenient nature of the format yields a more serious concern for the format's sustainability. Adoption, or "the degree to which the format is already used by the primary creators, disseminators, or users of information resources," is one of the key criteria identified by the Library of Congress' Sustainability of Digital Formats initiative.[110] If a format is widely adopted, it is less likely to become obsolete. Therefore, if software developers write programs that do not support the JPEG standard, it becomes increasingly more difficult for the format to become widely adopted, thus imperiling the format's long-term viability.

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108 Dirk Van Dall, "Digitizing, JPEG2000, and 'usability,'" AMIA-Listserv, May 12, 2006, accessed March 5, 2013, http://lsv.uky.edu/scripts/wa.exe?A2=ind0605&L=AMIA-L&P=R20987&I=-3.

109 Gordon E. Moore, "Cramming More Components onto Integrated Circuits," *Electronics* 38, no. 8 (April 19, 1965), accessed May 6, 2013, http://download.intel.com/museum/Moores_Law/Articles-Press_Releases/Gordon_Moore_1965_Article.pdf.

110 Library of Congress National Digital Information Infrastructure and Preservation Program (NDIIP), "Sustainability of Digital Formats: Planning for Library of Congress Collections," Sustainability Factors, accessed March 02, 2013, http://www.digitalpreservation.gov/formats/sustain/sustain.shtml.

Another facet of this problem is the fact that JPEG 2000 decoding is not native to web browsers,[111] which is significant for two reasons. In an article that addresses several preservation risks of the JPEG 2000 format as it applies to still images, Chris Adams, the technical lead for the World Digital Library at the Library of Congress, claims that browser support for a format is critical because,

> Users are increasingly using browsers to perform tasks that used to be considered solely the domain of traditional desktop applications, […] a trend which will continue as HTML5 makes increasingly advanced web applications possible. In practice, this means that any image format which cannot be viewed directly in the average web browser will become a support burden for site operators and it becomes correspondingly tempting to adopt a storage format such as PNG or JPEG since most images will eventually need to be transcoded into those formats for display.[112]

Adams goes on to observe that this in itself does not necessarily present a preservation risk, rather an obstacle that will add another layer to the already complex preservation strategy that will be required for this format. Although Adams is talking about still rather than moving images, the issues Adams brings up are the same for both the latter and the former.

The lack of browser support is significant because it "ensures that JP2 is almost non-existent on the web and thus is not a factor in most software selection decisions."[113] Because, "our future ability to read a file is a function of how widely it is used," Adams argues that JPEG 2000 is in the "unfortunate position of having limited use outside of a few niches," and that its limited adoption may imperil the long-term sustainability of the format.[114]

Concerns of the limited adoption of the format extend beyond the dearth of application and web-based support. The format profile for JPEG 2000 under the Library of Congress' Sustainability of Digital Format initiative notes that, "JPEG 2000 encoding is not generally built into still-photography camera chips,"[115] and until the format is widely adopted within the field of image acquisition it is likely that there will not be sufficient demand for hardware and software that incorporate the format.

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111 Library of Congress, "JPEG 2000 Part 1 (Core) Jp2 File Format," Sustainability of Digital Formats, Sustainability Factors: Adoption, accessed February 16, 2013, http://www.digitalpreservation.gov/formats/fdd/fdd000143.shtml.

112 Chris Adams, "Is JPEG-2000 a Preservation Risk?," The Signal: Digital Preservation, January 28, 2013, accessed February 16, 2013, http://blogs.loc.gov/digitalpreservation/2013/01/is-jpeg-2000-a-preservation-risk/.

113 Chris Adams, "Is JPEG-2000 a Preservation Risk?"

114 Chris Adams, "Is JPEG-2000 a Preservation Risk?"

115 Library of Congress, "JPEG 2000 Part 1 (Core) Jp2 File Format."

Mazzanti, an early supporter of the JPEG 2000 format, sees its sluggish rate of adoption as a concern. In 2002 at the outset of the EDCINE project, on ongoing effort that is focused on optimizing and enhancing the digital cinema experience across Europe, Mazzanti says, "I was the one who was very much in favor of using JPEG as a long-term storage format," but that, "Nowadays I'm less keen because it's not as widely used as I hoped it would be by 2013."[116]

However, it should be noted that in spite of the niche adoption of the JPEG 2000 in certain cultural arenas, the Library of Congress also observes that, "there is increasing implementation of JPEG 2000 in archive and library digitization," citing NASA's decision to use the format in their High Resolution Imaging Science Experiment on board the Mars Reconnaissance Orbiter in addition to the Digital Cinema Initiative's selection of JPEG 2000 in their original Systems Specification.[117]

If these standards remain stable and JPEG 2000 continues to be the only sanctioned file format for digital cinema well into the future, then the Library of Congress is right to express optimism regarding the recent groundswell of support for this format. Unfortunately is impossible to predict the future, and it is all too likely that these standards will evolve as time passes. Hence for the time being the relatively niche adoption of the JPEG 2000 format presents a potential risk to the format's sustainability.

Complexity

Chris Adams addresses another aspect of the JPEG 2000 format that raises concerns about its suitability as long-term archival format. Discussing the intricacy of JPEG 2000, Adams notes that, "the complexity of the format and the restricted specification provide many opportunities for developers to produce malformed files or fail to decode correct but obscure options."[118] For Adams, the complexity of the JPEG 2000 standard can be problematic. Adams observes that not only can this lead to the creation of a malformed JPEG 2000 file that applications don't detect, it can also result in the creation of a well-formed file that applications fail to recognize because they can only understand a limited aspect of the JPEG 2000 specification.

For all of these reasons, JPEG 2000 is not an ideal format for long-term preservation.

MXF

The Material eXchange Format (MXF) is an open file "container" or "wrapper" format standardized by SMPTE that was designed by audiovisual professionals aimed at the interchange of audiovisual material with associated metadata. According to a paper by Bruce Devlin published in the EBU Technical Review, "[MXF] has been designed and

[116] Nicola Mazzanti, "Interview with Nicola Mazzanti."
[117] Library of Congress, "JPEG 2000 Part 1 (Core) Jp2 File Format."
[118] Chris Adams, "Is JPEG-2000 a Preservation Risk?"

implemented with the aim of improving file-based interoperability between servers, workstations and other content-creation devices."[119] The format supports different bitstreams of coded "essence" and includes a metadata wrapper that describes the material contained within the MXF file. In the case of DCPs, the essence includes audio, video, and text files. Because the file's usability depends upon these various elements remaining in sync, wrappers are necessary to package and bind these elements together so that they remain aligned.

Too Many Variables

The format's creators designed MXF to have a great deal of flexibility, which they hoped would enable the format to be used as a wrapper for a large combination of varying file types. Therefore, the MXF standard leaves both the format's essence container and the descriptive metadata undefined, instead designating requirements for these components to be added as plug-ins to an MXF file.[120] The capacity to plug-in essence and metadata to an MXF file is a benefit because it enables the format to be used for a wide variety of purposes and within many different working environments within the audiovisual community.[121]

But while the format's versatility is one of its most significant assets, it is also represents one of the format's greatest weaknesses. The plug-in feature yields a vast number of variables that the software and hardware responsible for reading the MXF file must take into account. The consequence implied by this flexibility is a corresponding risk regarding the interchange, or the exchange of data, within an MXF file. SMPTE implemented a number of additional MXF standards to address this problem that specify the placement of the essence container within the MXF wrapper.

Although standardizing the essence mappings helps promote interchange between two hardware or software systems that share a common codec, according to the Federal Agencies Audio-Visual Digitization Guidelines Working Group, "the variations in structure may still create interchange obstacles if there is not a common mechanism for communicating and interpreting structural metadata."[122] Due to MXF's universal nature, the absence of a common codec to properly communicate and interpret structural metadata is not uncommon. Moreover, even in presence of a common codec, interchange may be negatively affected depending on how various applications interpret, adapt, or implement the SMPTE standards governing structural metadata.

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[119] Bruce Devlin, "MXF — the Material EXchange Format," *EBU Technical Review*, July 2002, accessed March 2, 2013, http://www.media-matters.net/docs/resources/Wrapper-Container%20File%20Formats/MXF/MXF.pdf.

[120] Society of Motion Picture & Television Engineers, SMPTE 377M-2004: Material Exchange Format (MXF) — File Format Specification (Standard).

[121] Al Kovalick, "A Quick Tour of Wrappers and MXF," white paper, Advanced Media Workflow Association, 2012, accessed March 2, 2013. http://www.amwa.tv/downloads/whitepapers/AMWA_MXF_wrappersKovalick1-2012.pdf

[122] Carl Fleischhauer et al., "Audio-Visual Format Documentation Project: Background Paper," Federal Agencies Digitization Guidelines Initiatives: Guidelines: MXF Application Specification, October 7, 2010, accessed March 2, 2013, http://www.digitizationguidelines.gov/guidelines/FADGI-AV_AppSpecProj_Bkgd_101007.pdf.

Interoperability Concerns

The most significant consequence of this is the potential for interoperability issues with MXF files across different hardware and software platforms. Thus, in order to create an application that solves particular interchange problems, SMPTE developed a series of standards that identify different 'classes' of complexity among audiovisual files, assigning each class its own Operational Pattern (OP).[123] Each OP will have a distinct arrangement based on an anticipated workflow, thus enabling the file to signal its distinct level of complexity to a decoder. For example, OPAtom was designed for applications that require a simple MXF file consisting of a single essence track, while OP-1A is more robust and allows for multiple, interleaved tracks of image and audio essence.

The profile of every OP is unique, allowing decoders to be purpose-built for different OPs of varying complexity. Adhering to these Operational Patterns was intended to provide a solution that would ensure interchange across various applications and prevent problems with MXF interoperability. However, this has not been the case: "Files created by products from different manufacturers may vary significantly in their structure and contents, even if they comply with the same Operational Pattern specification."[124]

Ernesto Santos describes this problem in a 2007 paper that he presented at the National Association of Broadcasters engineering conference:

> The market is being flooded with MXF products, each using MXF in the configuration that suits best that product's application. For this reason, questions such as "which MXF flavor is this?" or "whose MXF is this?" are becoming quite common.[125]

Santos addresses the fact that although vendors were implementing MXF, they frequently added proprietary aspects to the Operational Patterns that exacerbated problems with interoperability.[126] These additions sometimes resulted in interoperability issues that could also occur in an archive depending upon how the file is wrapped and what applications the archive used.

Incompatibility Concerns

An additional challenge with regard to the MXF format is that the initial SMPTE standard defining the MXF's Generic Container, SMPTE ST 379, was recently split into two distinct

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[123] Society of Motion Picture & Television Engineers, "Proposed SMPTE Engineering Guideline for Television – Material Exchange Format (MXF) Engineering Guideline (Informative)," white paper, SMPTE, 2003, accessed March 2, 2013, http://avwiki.nl/documents/eg41.pdf.

[124] Avid, "MXF Unwrapped," 2006, MXF Operational Patterns, accessed March 3, 2013, http://www.avid.com/static/resources/common/documents/mxf.pdf.

[125] Ernesto Santos, "Operational Patterns… the MXF Flavors?," MOG Solutions, 2007, accessed March 2, 2013, http://www.mog-solutions.com/img_upload/PDF/MOG_SOLUTIONS_operational_patterns_NAB2007.pdf

[126] Chris Lacinak, "MXF Interoperability," e-mail message to author, January 9, 2013.

standards, SMPTE ST 379-1:2009 and SMPTE ST 379-2:2010. According to Chris Lacinak, "The former maintains compatibility with the original 379, but the latter allows deviation (in support of added flexibility) that will create incompatibilities between 379 and 379-2."[127]

All of these factors make MXF problematic with regard to the long-term preservation of DCPs, leaving its content vulnerable to the shortcomings of this wrapper.

Unstable Standards: Interop DCPs and the Inevitability of Change

There are two halves to this problem. The first has to do with DCP standards as they have evolved over the past decade, and the second has to do the rate at which standards for digital cinema will continue to evolve in the future.

Interop DCPs

Standards have been an essential component of the cinema almost since its inception in the early 1890s. Not only do standards help regulate the production of technology and encourage innovation across the field, but "without [standards]," as Leo Enticknap observes, the basic economic principle on which the film industry depends for profitability – that of reproducing a single recording in as many different locations and to as many different paying customers as possible – becomes less effective or even impossible."[128] In Enticknap's view, the importance of technical standards cannot be understated; they are elemental to the success of the film industry at large.

However developing standards is a process that typically occurs over many years, and establishing a set of standards for digital cinema has proved to be no exception to this rule. As discussed above, this was due to the absence of broad user input, which was impossible to collect given digital cinema's relatively small footprint in the years following its debut, and the manufacturer-driven market for digital cinema equipment that emerged as a result.[129] For studios that were eager to distribute their product digitally, waiting to begin manufacturing DCPs until a standard for the format emerged was not a viable option. Therefore in the interim, it was agreed that all DCPs, in addition to the servers and projectors off which they played, would be required to meet an informal specification called "Interop."

[127] Chris Lacinak, "MXF Interoperability."
[128] Leo Enticknap, *Moving Image Technology: From Zoetrope to Digital*, 160.
[129] Michael Karagosian, "New Studio Coalition To Look Into Standards: NewCo Digital Cinema: Tech Issues Come Home to Roost".

According to Karagosian, "The Interop DCP … is based on simplified and early standards drafts to promote interoperability in the early phase of the digital cinema rollout."[130] Intended as a stopgap measure until SMPTE's standards were published, Interop DCPs are not compliant with SMPTE's DCP standards, nor do they support many of its features. Paradoxically, in the absence of any other set of standards, Interop became a standard entirely in and of itself.[131] However, in spite of being conceived as a temporary solution, "Interop's lifetime in the field has far exceeded what was intended."[132] As of late 2011 this format was still in use, and, "no studio was consistently sending out films in the SMPTE standard."[133]

Although now considered a legacy format, having been in widespread use for nearly a decade, Interop DCPs have become ubiquitous. Preserving this format will pose a significant challenge to preservationists in the future because the differences between Interop and SMPTE DCP standards are substantial, but not always apparent. Among the most significant of these differences, the Inter-Society Digital Cinema Forum (ISDCF), an open discussion forum dedicated to digital cinema comprised largely of individuals and companies working within the film industry, cites differences in XML namespace, requirements for content, partitioning, and KDM and Certificate validation.[134]

Naming Conventions (Or a Lack Thereof)

An example of how these differences have already begun to cause problems for preservationists lies in is the lack of any standardized naming convention of the digital cinema file. As the ISDCF explains, initial gaps in both the Interop and the SMPTE standards resulted in the evolution of different uses of the metadata fields within the Composition Playlist. Consequently, "in the absence of consistency, … the text applied to the ContentTitleText element of the Composition Playlist in both SMPTE DCP and Interop DCP has significantly evolved,"[135] leading to inconsistent iterations of a film's title. Moreover, Jim Whittlesey reports that while, "most everyone" uses the ContentTitleText field in the CPL as the default for displaying a film's title, however the use of this field is, "not always completely 'correct'," implying that variation and inconsistency within this field are *de rigueur*.[136]

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[130] Michael Karagosian, "Are SMPTE Standards Used in Distribution Today? If Not, Then How Is Content Distributed?," Digital Cinema Technology Frequently Asked Questions (FAQs), accessed March 03, 2013, http://www.mkpe.com/digital_cinema/faqs/tech_faqs.php.

[131] For a comparison

[132] Michael Karagosian, "Digital Cinema Experiences Strong Growth in 2011 - a Mid-Year Report," *SMPTE Motion Imaging Journal* 120, no. 6 (September 1, 2011): 47, accessed March 3, 2013, doi:10.5594/j18082.

[133] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 86.

[134] Inter-Society Digital Cinema Forum (ISDCF), "ISDCF Recommendation SMPTE DCP and Interop Requirements," Technical Documents, December 23, 2010, Digital Cinema Naming Convention, accessed March 3, 2013, http://dcinemacerts.net/dcinematools.com/images/tech_upload/SMPTE_DCP_and_Interop_Requirements_2010-12-23_MKPE.pdf.

[135] Inter-Society Digital Cinema Forum (ISDCF), "ISDCF Recommendation SMPTE DCP and Interop Requirements."

[136] Jim Whittlesey, "MIAP Thesis on DCPs," e-mail message to author, March 14, 2013.

The title of a DCP is a crucial piece of metadata, and it would be simple for future preservationists who are not aware of this inconsistency to mis-label or mis-identify the title of a movie that has been recorded in the absence of a standard or under a version of a standard that has since become obsolete. Therefore, collecting information about the standard under which a DCP was produced will provide essential information about the content of its files. However, currently this practice is not common among archives. Moreover, as the above example suggests, knowing in accordance with which standard a DCP was made does not preclude the possibility that there will be a degree of variation in how each standard was implemented. Therefore, procuring this information is not a guarantee that the implementation of the data or metadata will be identical between Interop DCPs. For Mazzanti, this will prove a significant challenge. “I have no clue what will happen and how [the Interop will] perform down the line. … They were made in another world, so they may not work anymore.”[137]

Evolution of Standards

Another problem that preservationists face with regard to DCPs will be the rate at which digital cinema technology will continue to develop, which will in turn result in new standards and recommendations over time.

Few standards are born fully formed; it is common for amendments and errata to appear in the years following a standard’s introduction as those tasked with its implementation discover shortcomings that require address. Predictably, in the seven years since SMPTE formally standardized the DCI’s specifications for DCPs there have been a number of changes to the standard. Evidence of these modifications can be gleaned both from the Errata section of the DCI’s website, which number over 2000 as of March 2013,[138] and also from browsing the long and ever growing list of standards on SMPTE’s website under the “D-Cinema” category.[139]

In the digital universe, change is the only constant.

> Rapid obsolescence of computer hardware has been a signature characteristic of the industry since its inception over 50 years ago. A one or two order of magnitude improvement in power, speed, efficiency, or cost per value has occurred every several years in areas such as CPU speed, memory

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[137] Nicola Mazzanti, “Interview with Nicola Mazzanti.”

[138] Digital Cinema Initiatives, LLC, “Archives,” Digital Cinema Initiatives, Archived March 8 2008 Specification 1.2 plus errata from March 8 2008 through August 30 2012, accessed March 03, 2013, http://www.dcimovies.com/archives/spec_v1_2_No_Errata_Incorporated/index.html.

[139] Society of Motion Picture & Television Engineers, “Searching Standard Content for D-Cinema in Subject,” SMPTE Standards: Browse by Topic, accessed March 03, 2013, http://standards.smpte.org/search?smptes-subject=D-Cinema. There are 50 distinct standards that are currently tagged with “D-Cinema” as a searchable keyword, however this does not include standards that pertain to aspects of digital cinema, for example standards that relate to the MXF format.

> chip density, storage device capacity, video processing rate, and data transmission rate.[140]

These advances in technology manifest themselves in newer computers that feature a variety of qualitative functions that earlier technology did not allow, which in turn enables the development of applications that take advantage of these features. This results in new file formats and software that ultimately supersede their older, less advanced predecessors, causing older file formats and software to become obsolete. Because new software is typically built to run on only the most recent hardware, older, less advanced hardware quickly becomes obsolete. Added to this problem is the fact that newer technology often introduces ancillary features, for example CD drives, which helps contribute to the obsolescence of the technology (floppy discs) that preceded it.

Thus, the constant evolution of file formats, hardware, and software will be inevitable as long as computer technology continues to advance. Just as what was possible in the arenas of image acquisition, post-production, and exhibition have changed dramatically over the past two decades, the technology governing all of these fields in the future will be substantially different from what is available today. Moreover, these changes may not be insubstantial, and it is possible that they will have profound affects on the system architecture of digital cinema exhibition at large. For example, the most significant change currently on the horizon is the advent of laser technology for digital cinema exhibition. In 2012, rival companies Christie and Barco, the two largest manufacturers of digital cinema projectors, each debuted laser projection technologies that, they have announced, will be at the center of their research and development efforts in the coming years.[141, 142]

If, or perhaps when laser technology supersedes the DLP projection technology currently in use for digital cinema exhibition, it will be likely demand that the standards evolve to accommodate these changes. Should this occur, it will put all the DCPs made prior to the changeover at a greater risk for format obsolescence because all the hardware and software associated with creating, managing, and playing back DCPs will have to continuously evolve alongside these advances to meet the new standards. However the more a standard evolves, the greater a challenge it will present for future preservationists to manage, thus potentially causing problems.

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140 Cornell University Library Research Department, "Obsolescence: Hardware and Media," Digital Preservation Management Workshops and Tutorial, Introduction, accessed March 06, 2013, http://www.dpworkshop.org/dpm-eng/oldmedia/obsolescence2.html.

141 Christie Digital Systems USA, Inc., Press, "World's First Laser-Projected Screening of Full-Length Movie Debuts With Christie Laser Projector; 2D Light Levels Achieved for 3D at IBC 2012 'Big Screen' Event," news release, September 6, 2012, Press Releases, accessed March 5, 2013, http://www.christiedigital.com/en-us/news-room/press-releases/pages/worlds-first-laser-projected-screening-of-full-length-movie-debuts-with-christie-laser-projector.aspx.

142 Barco, Inc., Press, "Barco Showcases Groundbreaking 4K Laser Projection among Numerous Technology Firsts Launched at CinemaCon," news release, May 15, 2012, Press Releases, accessed March 5, 2013, http://www.barco.com/en/News/Press-releases/barco-showcases-groundbreaking-4k-laser-projection-among-numerous-technology-firsts-launched-at-cine.aspx.

Carriers

As discussed above, the introduction of new technology spurs the obsolescence of earlier hardware and software, ultimately putting older carriers at risk of becoming obsolete. However the threat of a carrier's failure presents a more immediate, and therefore a more serious, concern. The readability of a carrier—a hard drive in the case of DCP—can be affected by a number of factors, including macro-environmental concerns like the presence of dust or humidity, material instability, hardware malfunctions, infrequent use, or human error. However even hard drives stored in ideal conditions will fail at some point, and best estimates point to an average lifespan of no more than 7 years.

In addition to the inevitability of hard drive's failure, the fact that DCPs can be stored on a wide variety of media constitutes added concern. This is problematic because, as Jon Elerath explains, "there are significant differences [of failure rates] across suppliers, and great differences within a specific [hard drive] family from a single supplier. These inconsistencies are further complicated by unexpected and uncontrolled lot-to-lot differences."[143] Because the failure rates of hard drives are inconsistent, it is impossible for an archive to prioritize hard drives brand or vintage even if this information is known (which may not always be the case).

For Karen Barcellona, the Digital Curator at the Academy Film Archive, the quality and variety of the media on which DCPs were being produced was a problem.

> Early on DCPs were identified as a pressing preservation concern because they come to us on whatever media the filmmaker delivers it on to us. And this has meant all manner of external hard drives, flash drives… there was one motion picture that came to us on a little keychain thumb drive and the title of the film was on the thumb drive [itself].[144]

While Barcellona's comment correctly implies that a consumer-grade thumb drive does not represent the ideal physical storage medium for a DCP's long-term preservation, as Elerath points out, in the long-term these drives are not necessarily less vulnerable to failure than any other carrier. Thus, Barcellona's instinct to classify all DCPs as a preservation concern is a good one, and highlights the need for preservationists to be aware of the risks involved in storing DCPs on the hard drives upon which they were received.

Encryption

For DCI members tasked with establishing the systems architecture for digital cinema, the ability to encrypt a DCP in order to protect its content from piracy was of paramount concern. The rise of peer-to-peer downloading resulting from the increasing prevalence of

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[143] Jon Elerath, "Hard-Disk Drives: The Good, the Bad, and the Ugly," *Communications of the ACM* 52, no. 6 (2009): 41, accessed April 3, 2013, http://cacm.acm.org/magazines/2009/6/28493-hard-disk-drives-the-good-the-bad-and-the-ugly/fulltext.

[144] Karen Barcellona, "Archiving and Preserving Digital Cinema Packages," Presentation, Association of Moving Image Archivists Conference, Seattle, December 6, 2012.

broadband internet connections had contributed to making film and music piracy, “the single greatest threat to the world’s entertainment industries,”[145] and the studios were insisting on accordingly heavy security features that would prevent pirates from gaining access to the digital cinema files at any point during the DCP’s journey to the theatre and back.

The studios’ demand for a heavy encryption protocol was initially met with resistance from theatre owners, who argued that the measures would fundamentally alter their ability to conduct business as usual.[146] However the studios dug in their heels, and the intricate security measures they demanded were ultimately adopted into the DCI’s recommendations.

How DCP Encryption Works

Published in July 2005, the DCI’s “Digital Cinema System Specification Version 1.0” established the same security encryption measures as those used by the U.S. military to protect sensitive information,[147] and by banks to protect online transactions.[148] In addition to heavy encryption, the specifics of which will be discussed at length below, other security measures built into the DCI’s System Specifications included the use of software within the DCP that is able to log every usage; an authentication procedure based on unique certificates that prevents a DCP’s content from playing on an unrecognized device; a forensic marking system that places an invisible watermark on the image and audio of a film that allows instances of piracy to be traced back directly to the location of its theft; and a series of “dark screen rules” that will automatically shut down the system and prevent the film from playing if any of these sub-systems are tampered with or not functioning correctly.

Ultimately, however, the most significant of these security measures is the encryption placed on the image and audio files. The Systems Specification requires the use of the Advanced Encryption Standard (AES) encryption, which is a free, widely used cipher established by the National Institute of Standards and Technology (NIST) in 2001. AES is a symmetric cipher, meaning that the keys used to both encrypt and decrypt a piece of information are identical.

AES encryption works by attaching a randomly generated 128-character number to basic data—image and audio files, for example—known as plaintext, and then using a series of

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[145] Eric Priest, “The Future of Music and Film Piracy in China,” *Berkeley Technology Law Journal* 21, no. 795 (2006): 795.

[146] David Bordwell, *Pandora’s Digital Box: Films, Files, and the Future of Movies*, 61.

[147] TechTarget, “Advanced Encryption Standard (AES),” Search Security, February 2011, accessed May 06, 2013, http://searchsecurity.techtarget.com/definition/Advanced-Encryption-Standard.

[148] A pamphlet issued by the Digital Servicing and Distribution arm of Deluxe Laboratories in London declares that “The encryption level is equivalent to that used by The Bank of England….so if you can hack a DCP you may as well hack the bank…!” Deluxe Digital London, "Digital Cinema – Some Descriptions," Digital Servicing & Distribution, Key Delivery Message - DC Clones, accessed May 4, 2013, http://www.deluxedigital.co.uk/assets/pdf/DDL_Useful_Descriptions.pdf.

algorithms to scramble the information, which changes the data into a code known as ciphertext. Unscrambling the code requires the original 128-character number, known as a 'key.' Because the scrambled 128-character number yields 2^{128}, or 340,282,366,920,938,463,463,374,607,431,770,000,000, numerical possibilities, given current computing speeds it is impossible for an average pirate to crack the code using a "brute force" method (i.e., trying every possible numerical combination in order to guess the key).[149] Moreover, even if a brute force attack is attempted and someone tried to hack into DCP without the key, the encryption files are programmed to render the content useless.[150]

AES encryption is applied to a DCP during the mastering process, after the image files have been compressed and sub-divided into individual reels, each of which is set up as a distinct folder that contains a set of files—one for image, one for sound, and one for subtitles or timed text.[151] After a reel has been built, all of its files are wrapped using MXF to create a single 'track.' Finally, each MXF track is encrypted with AES 128-bit encryption, and the keys are placed in a secure database that must be periodically backed up. Ultimately each encrypted MXF track will require a unique 'key' to unlock it contents.

However, in order to ensure the protection of these keys, the AES keys must themselves be encrypted. This is accomplished by using a second, substantially different public domain cryptographic algorithm called RSA. Unlike AES, the RSA cipher is asymmetric, meaning that the key used to encrypt the information will be different than the keys used to decrypt the information. RSA, invented in 1977, is based on the presumed challenge of factoring large integers.

The RSA algorithm is mathematically complex. The algorithm,

> creates and then publishes the product of two large prime numbers, along with an auxiliary value, as their public key. The prime factors must be kept secret. Anyone can use the public key to encrypt a message, but with currently published methods, if the public key is large enough, only someone with knowledge of the prime factors can feasibly decode the message.[152]

For digital cinema distributors, the practical application of this algorithm is that RSA encryption requires a new set of keys to be generated for every single instance of use. This allows studios to maintain tight control over their films by authorizing each individual

[149] Despite its strength, the AES algorithm is not perfect; researchers from the University of Leuven, École Normale Supérieure, and Microsoft have identified some weaknesses in its structure. However, due to the vast number of numerical combinations required, the attack designed by these researchers to break the code has no practical implications on the security of user data. Help Net Security, "Researchers Identify First Flaws in the Advanced Encryption Standard," Help Net Security, August 17, 2011, Spotlight, accessed May 06, 2013, http://www.net-security.org/secworld.php?id=11474.

[150] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 94.

[151] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 88.

[152] "RSA (algorithm)," Wikipedia, June 05, 2013, RSA (algorithm), accessed May 06, 2013, http://en.wikipedia.org/wiki/RSA_%28algorithm%29.

instance of a DCP's use. This authorization is accomplished by issuing a "Key Delivery Message" (KDM), as described above.

Key Management

Although a DCP can ostensibly be encrypted at any point after it has been made, typically encryption is applied at the point of their creation. Moreover, while it is technically possible for amateur and independent filmmakers to encrypt a DCP on a home computer using free, open source software, this option entails a variety of risks associated with key management. Managing the keys required to unlock an encrypted DCP over time is a complex chore that requires an appropriate infrastructure—secure databases that must be periodically backed up—and significant resources. Therefore, it is more common for encrypted DCPs to be manufactured by trusted third parties that will manage keys for a fee.

As Jim Whittlesey of Deluxe explains, "We generate and distribute [the] KDM based on booking orders from the content owner. So we are responsible to make sure the KDM is deliver[ed] and [that the] theater can play the movie according to the rules in the KDM."[153] In this scenario, Deluxe assumes responsibility for the keys in perpetuity, which in turn requires the content owner to pay Deluxe a fee for this service. Although the content owner is hypothetically free to assume the responsibility for managing these keys at any point, doing so would require the content owner to have access to the appropriate software in addition to implementing a management strategy that might include a secure storage environment and double line redundancy. Meeting these criteria is not easy for most filmmakers, most of whom prefer to allow digital cinema laboratories to assume this responsibility on their behalf.

Problems with Encrypted DCPs

Without the appropriate KDM, the server will be unable to ingest the DCP's content. It is for this reason that a white paper published by the Technical Commission of the Fédération Internationale Des Archives Du Film (FIAF) claims that, "as an archive element the DCP is only useful for the archive if it also holds the [KDM containing the] AES keys that were used to encrypt the image and sound track files. An encrypted DCP without keys is of no use at all because it can not even be played back."[154]

Thus, encryption poses a serious problem for preservationists: without the keys required to unlock a DCP, encryption will render its content wholly inaccessible, and therefore completely useless. In spite of this fact, thus far there has been nearly a wholesale unwillingness on the part of both independent filmmakers and studios alike to allow unencrypted DCPs out of their control. Their refusal stems from fears relating to piracy. As Andrea Kalas, Vice President of Archives at Paramount Pictures, explained,

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[153] Jim Whittlesey, "More Questions for Jim Whittlesey."
[154] Arne Nowak, "Digital Cinema Technologies from the Archive's Perspective," 11-12.

> We don't share unencrypted copies outside of the archive; our archive is the only place where unencrypted copies live, because the concept is that from unencrypted copies we can make new digital cinema prints. They're the raw material for making new copies, and so for that reason, we wouldn't want to give up the capability of creating new digital cinema prints to anyone other than ourselves, because it's our property. It's our movie. […] It's a business. We make movies for money. That's why we encrypt them, because people pay money to see them. That's the point.[155]

Kalas' response is typical of the attitude adopted by the film industry at large: Content creators perceive piracy as a mortal threat that has severely affected their bottom line, and therefore they are unwilling to accept the risks associated with allowing an unencrypted DCP outside their control, regardless of whether their destination is a movie theatre or an archive. In fact, many studios have gone so far as to initiate policies that forbid the deposit of unencrypted DCPs at archives under any circumstances. As Jon Wengström, the Curator of Archival Film Collections at the Swedish Film Institute, explains,

> The transition from 35mm to DCP distribution has led to a complete halt on the deposit of foreign films released in Sweden. We used to get one or two viewing prints when distribution rights expired of everything screening in Sweden—American films, French films, Iranian films, whatever. We have been approached by Swedish distributors of foreign films saying, 'now that we are releasing our films on films on DCP do you still want a copy?' And we say 'yes, if it's unencrypted.' And they say 'we are not allowed to deposit unencrypted DCPs, only encrypted DCPs.' … Usually we receive every year around 200 prints of foreign films, but since August last year [2012] we haven't received anything. This was always a voluntary deposit; no one was obliged to do it. But the system worked pretty well. Now with the change to digital they only offer us [encrypted DCPs], and we say we don't accept it.[156]

Disallowing the deposit of unencrypted DCPs will have a profound affect on institutions around the world like the Swedish Film Institute that depend on voluntary deposits from the Hollywood studios. If the status quo regarding the industry's refusal to deposit unencrypted DCPs persists, it may eventually lead to an alteration of their collecting policy.

This is significant because for many institutions this would imply changing their very mission. For example, in the case of the Swedish Film Institute, their mission is to, "collect, catalogue, preserve and give access to Sweden's film heritage, by which we mean all Swedish and foreign films released in cinemas in Sweden: feature films, non-fiction films, animations, commercials, news-reels etc."[157] For Wengström, the position that studios have adopted regarding encryption poses a profound existential dilemma.

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[155] Andrea Kalas, "Interview with Andrea Kalas," interview by author, December 6, 2012.

[156] Jon Wengström, "Interview with Jon Wengström," telephone interview by author, February 20, 2013.

[157] Swedish Film Institute, "About the Archive," Archival Film Collections, November 28, 2008, accessed March 07, 2013, http://www.sfi.se/en-GB/Film-Heritage/About-the-archive/.

> We feel of course that foreign films released in Sweden [are] also part of Swedish heritage because they influence the culture here a lot. Of course our main concern has always been the Swedish films because they wouldn't be preserved elsewhere, but we also have found that its very important to preserve the distribution prints that were in Sweden … because they have been a very big part of Swedish culture.[158]

If the status quo regarding the studios' refusal to deposit unencrypted DCPs persists, it threatens to fundamentally alter the Swedish Film Institute's mission statement because they will be unable to preserve content to which they have no access.

Finally, the studios' refuse to compromise thus far has already resulted in ramifications beyond merely the encryption of their own material. Poalo Tosini, a consultant at the Cineteca Nacional de México, reports that although the Cineteca has intentionally tried to insist on producing unencrypted DCPs in-house, they have been stymied by what Tosini refers to as "big cinema chains" that "are not able to accept unencrypted materials."[159] This is likely because cinema chains are typically set-up for projecting studio fare, all of which will be encrypted. This serves to effectively create and reinforce a standard for encrypting DCPs, which, in this case, will affect the Cineteca because they will be forced to encrypt their content as well.

Bugs and Kinks

DCPs are a new technology that, as described above, has evolved tremendously over the course of the past decade, and will likely continue evolving at a steady rate in the near future. Alongside the establishment of the systems infrastructure and technical specifications for DCPs has been the development of a number of new software applications that have been built to create, manage, and play DCPs. However like any fledgling technology, these have proved to contain some kinks, resulting in DCPs sometimes feature mysterious errors whose causes are unknown.

The occasional presence of these errors, which usually render a DCP unplayable, has been a recurrent theme throughout the interviews that I have conducted for this thesis. Nicola Mazzanti describes a scenario that has been typical among a number of individuals with whom I have spoken:

> We got a DCP once that opened at one point, and then stopped, went blank, and then stopped. And then if you moved forward … after one minute [and ten seconds] … it starts playing again. But if you [restart] the server, it stops and then it's dead. It appears to be a problem with the encoding of the JPEG, but nobody knows what it is.

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158 Jon Wengström, "Interview with Jon Wengström."

159 Poalo Tosini, "MIAP DCP Thesis," e-mail message to author, April 3, 2013.

The discovery during playback of an error whose origins are unknown appears to be a common occurrence, and was reported for both DCPs produced by labs as well as for those that were made homemade on consumer-grade software. Due to the variety of software available to create DCPs and the different hardware in use to play them back, locating the origin of these problems has been futile. Identifying the source of these errors has been made more difficult in Europe by the lag that often occurs between a film's initial release and its deposit in an archive.[160]

As these software applications mature, the bugs and kinks that result in the creation of faulty DCPs may be smoothed out over time, causing the occurrence of these initial errors to be reduced. However, digital cinema technology evolves at a rapid rate, and the introduction of new software to meet these changes will result in the appearance of a brand new set of new bugs and kinks that will cause problems to occur. The existence of these errors poses a significant risk to preservationists.

But in addition to difficult-to-identify errors that occur during playback, sometimes these software applications produce files that do not comply with SMPTE standards. According to Wengström, it is not uncommon for the Swedish Film Institute to receive a DCP that is not in the right color space, doesn't have the correct bit-depth, or features sound and image tracks that are not in sync.[161] Whether these problems were cause by bugs in the software itself or occurred as a result of human error is difficult to know. Nevertheless, this problem represents a danger for preservationist and highlights the importance of verifying that a DCP's metadata meets SMPTE standards.

Formatting

Every hard drive has a file system that defines how and where data will be stored, and formatting is the process through which a hard drive is prepared for data storage. While there are no formal standards that govern the formatting requirements of DCPs, the Inter-Society Digital Cinema Forum has recommended that, "the storage partition format should be EXT-3" for DCPs.[162] In practice, most DCPs are formatted in a Linux-based operating system using EXT-2 or EXT-3 file systems. If a DCP is formatted in Linux—which will almost exclusively be the case—accessing its files will be a challenge if preservationists use principally Mac or PC hardware. As Jim Whittlesey explains, "if you create your DCP on a Mac and write the DCP out to a hard drive with Mac file system, you can send the hard drive to the theaters but few will be able to mount/read the hard drive."[163]

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160 Jon Wengström, "Interview with Jon Wengström."
161 "Jon Wengström, "Interview with Jon Wengström."
162 Inter-Society Digital Cinema Forum, "Disc File Format," Disc File Format, May 6, 2010, (Slightly Expanded) Existing Recommendations, accessed May 05, 2013, http://www.isdcf.com/ISDCF/DiscFormat.html.
163 Whittlesey, Jim. "More Questions for Jim Whittlesey."

This happens because most digital cinema servers run on Linux operating systems. Although this problem is due to the formatting of the file system on disk rather than the Mac or Windows operating systems installed on the hardware, the two issues are tightly coupled because 'out of the box' computers (or digital cinema servers according to Whittlesey's example) typically aren't built to read non-native file systems. Without installing the appropriate driver in a Windows or Mac operating system, the Linux formatted disk and its content will remain inaccessible.

Peter Oleksik, Assistant Media Conservator at MoMA, experienced this problem shortly after MoMA began receiving DCPs. The DCPs MoMA received were formatted using EXT-2, and as Oleksik explains, "Because we're a Mac environment I had a lot of difficulty actually just mounting the drives. So in a virtual machine I had to boot Linux to see the material on the drives."[164]

Once the drive is mounted in a virtual machine, it will be possible to migrate the DCP's content onto another file system. Although mounting a DCP in a virtual machine or on a computer running Linux to view its file structure is not particularly challenging in and of itself, being able to perform this task in the future will require archives to maintain the appropriate technology that will be required to accomplish this task.

Versioning

As noted above, most DCPs will contain multiple works, each of which is known as a "Composition Playlist" (CPL). Usually the different CPL's will represent distinct versions of a film intended to play in different territories. For example, a DCP created for the European release of a film may contain several different CPLs that feature a common set of image files but have different audio tracks featuring dubs of the film in Spanish, French, and German.

While DCPs frequently contain multiple versions of a single film, several archivists with whom I have spoken have reported that they sometimes receive DCPs that do not contain the correct version of a film. As Mazzanti explains, "you get [a DCP] that's supposed to be subtitled in whatever language, and actually it is not subtitled, or it's subtitled in another language, or it is dubbed instead of sub-titled."[165] This poses a problem for preservationists because if future curators chose to program a particular title and it is discovered only after the fact that the DCP does not contain the appropriate subtitles. Even if the studio or individual to whom the film belongs still has access to the original source material in the future, there is no guarantee that the subtitles will still be accessible in the future.

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[164] Peter Oleksik and Katie Trainor, "Archiving and Preserving Digital Cinema Packages," Presentation, Association of Moving Image Archivists Conference, Seattle, December 6, 2012.

[165] Nicola Mazzanti, "Interview with Nicola Mazzanti."

Color Gamut

The color gamut of a digital cinema projector is the complete subset of colors that the projector is capable of reproducing. DCPs are designed for projectors that use Digital Light Processing technology, which is based on an optical semiconductor called a Digital Micromirror Device that rapidly modulates light generated by the projector's xenon lamp in order to display an image onscreen. As mentioned above, most in the industry believe that projectors based on solid state laser technology will eventually supersede the DLP projectors currently in use. Laser projectors have a significantly higher light output than xenon lamps, giving them a much wider color gamut, increased brightness, and a higher contrast ratio.[166] The change in projection technology will create an image that is strikingly different from that which a projector with a xenon lamp is capable of producing.

While these changes are all desirable from the perspective of a cinema exhibitor, they may create a problem for preservationists because the resultant shift in color gamut will fundamentally change the look of all DCPs that were made for display on earlier projection systems.

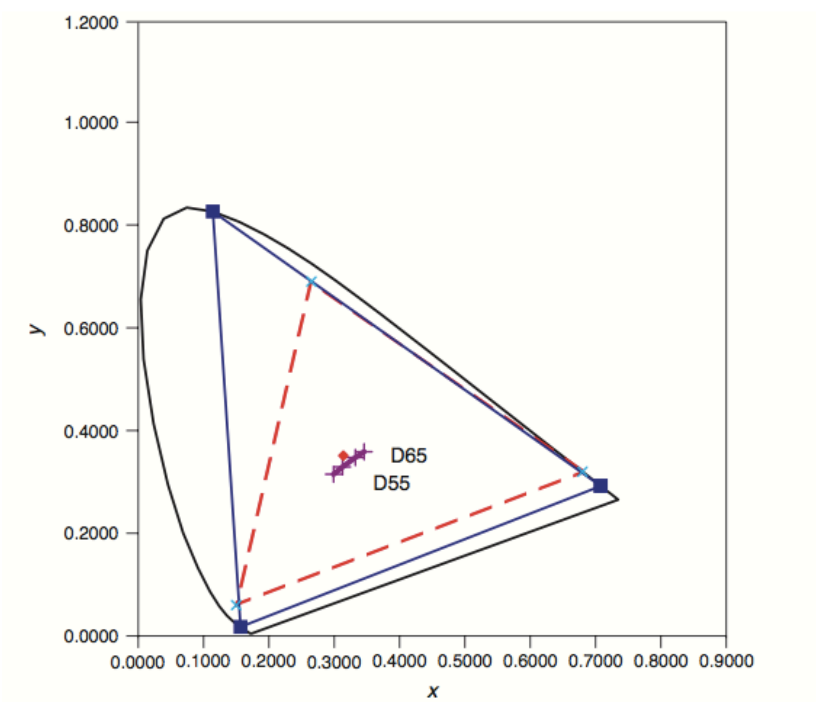

Figure 2. *Color Gamut of Xenon Lamp vs. Laser Technology* (2007) (*Color and Mastering for Digital Cinema*)

[166] Glenn Kennel, *Color and Mastering for Digital Cinema* (Burlington, MA: Focal Press, 2007), 172-173.

In the above graph[167], the black line illustrates the color gamut of standard 35mm film, the blue line represents the color gamut of a laser projector, and the dashed red line indicates the color gamut of a digital cinema reference projector with a xenon lamp. For Nicola Mazzanti, the difference between an image produced on a laser projector and an image produced on projector using a xenon lamp will be significant. Mazzanti refers to the inevitable evolution of the color gamut for digital cinema projection as the "most unpleasant" aspect of preserving DCPs because the look of any DCP has been determined with a particular color gamut in mind for its projection.

> "Whatever [Director of Photography] does color correction, it is designed for a certain display that, at the moment, is normally the digital cinema projectors based on the Texas Instrument [DLP technology] … But then when lasers or whatever [technology] there will be in the future [arrives], how will this stuff look?"[168]

Without the means to maintain the correct color gamut for a given DCP when it is projected, the images contained within the DCP will be forever altered. Although color management for DCPs will be difficult, it is crucial to consider the impact that future projection technology may have, and to work toward a preservation plan that will consider issues surrounding color management.

VII. Recommendations

Existing Resources

Although DCPs have been in existence since the mid-2000s, their limited use prior to around 2009 means that the format is still relatively new for the majority of the audiovisual archiving and preservation community. Consequently, few individuals within the field have begun to seriously consider the challenges surrounding this format. In spite of the fact that DCPs have grown in popularity over the past several years and are beginning to be common in institutions around the world, to date there are few resources that provide recommendations for the long-term preservation of DCPs, and no widely adopted best practices governing the preservation actions most appropriate to the format.

The three most important documents that address this subject are Nicola Mazzanti's article, "Goodbye, Dawson City, Goodbye: Digital Cinema Technologies from the Archive's Perspective: Part 2", and the FIAF Technical Commissions' "Digital Cinema Technologies from the Archive's Perspective" and "Recommendation on the Deposit and Acquisition of D-

[167] Kennel notes that in reality, "gamut is actually a three dimensional solid, with the third dimension being luminance," however luminance is not indicated above. Glenn Kennel, *Color and Mastering for Digital Cinema*, 23.

[168] Nicola Mazzanti, "Interview with Nicola Mazzanti."

cinema Elements for Long Term Preservation and Access v. 1.0." The former is an adept consideration of some concerns surrounding the transition to archiving DCPs that are presented as a set of lessons learned by Mazzanti and his colleagues at the Belgian Cinematek. Written by Arne Nowak on behalf of the Technical Commission, "Digital Cinema Technologies from the Archive's Perspective" (originally published in the AMIA Tech review as the first part to Mazzanti's article) limits itself to discussing issues surrounding encryption and playback. In a similar vein, the latter article written by the Technical Commission is an extremely brief set of recommendations that only address some of the archival considerations surrounding encryption. While both of these documents offer insight into DCPs that will be useful to archives as they begin to integrate this format into their collections, neither document addresses the handling of DCPs in practical terms.

The recommendations provided in this section aim to fill in some of these gaps by offering a set of practical guidelines for archives dealing with this format. Each of these recommendations falls into one of three distinct categories: The first concerns key steps that an archive should take or policies that an archive may consider adopting prior to acquiring a DCP; The second category involves actions that an archive should take upon ingesting a DCP into its collection; and the last category deals with measures an archive should take and initiatives that an archive may wish to pursue going forward into the future.

A result of my own research coupled with observations and advice gleaned from the interviews I conducted for this project with various audiovisual institutions around the world that already have substantial experience working with DCPs, the recommendations presented here are intended to mitigate some of the risks surrounding DCPs and thus help archives safeguard this format over the long-term.

Recommendations Prior to Acquiring a DCP

The widespread use of digital technology in film production and exhibition over the past decade has changed the way most film audiovisual institutions operate. Fossati cites "the need of accepting 'digital elements' as the 'original' masters of new film productions", "an increase in archives' capabilities [vis-à-vis digital restoration]", and the "urgent" need to "[digitize] film collections for access purposes" as being foremost among these changes.[169] In spite of the fact that the new emphasis on digital technology is steadily transforming film archives, many institutions have been slow to convert to becoming a fully-fledged digital repository. Consequently, many film archives and audiovisual institutions lack the capacity to manage the long-term stewardship of this information.

According to Brian Lavoie, this problem "is exacerbated by the relatively brief time horizon beyond which preservation of digital materials becomes an imperative, a consequence of the fragility of digital storage media, as well as rapid obsolescence of storage and rendering

[169] Giovanna Fossati, *From Grain to Pixel: The Archival Life of Film in Transition*, 63.

environments."[170] If this situation is not addressed, archives will find themselves with something of a crisis on hand. There are a number of steps that an audiovisual institution may take prior to acquiring digital material that will promote a stronger, more robust digital preservation system that may serve to prevent such a situation from occurring.

Define the Scope of an Archival Collection

While some film archives and audiovisual institutions that have begun to collect DCPs have given serious thought to their role with regard to collecting and preserving this type of content, others began acquiring DCPs without giving careful consideration as to whether or not it would be appropriate given their remit and resources. In *From Grain to Pixel*, Giovanna Fossati acknowledges this situation by noting that "film archives and film museums are struggling with questions about their role" in the face of the ubiquity of digital technology.[171] Locating the origins of this identity crisis in the ongoing debates surrounding the impact of digital technology on the medium, Fossati observes that the advent of digital cinema has given rise to two opposing points of view, once that treats the digital image as "a radical change in the nature of the medium, […] and the other that inscribes digital technology in a broader media landscape where film is one of the participants."[172]

Fossati's recognition of this Manichean divide is astute, and it is worth quoting her observations at length:

> In the past decade, the archival community has often embraced the first perspective, tracing it back to Bazin's reflection on the photographic image's unique power of transferring the "reality from the thing to its reproduction", a thesis dear to many film archivists. Taken to the extreme this approach fuels the idea that 'digital film' is not film anymore, and that it therefore represents the end of film as we know it. Accordingly, digitization would mark the end of film archives and museums, as they would stop collecting new material once analog photographic film disappeared.
>
> On the other hand, according to theories embracing the second perspective, the advent of digital technology does not mark the end of film and, therefore, film archives should continue collection, preserving, and presenting moving images on whatever medium, including the digital one. From this perspective transition is in itself much more complex and in a way integral to the panorama of the media.[173]

As Fossati's comments make evident, it is crucial that archives and audiovisual institutions clearly understand upon which side of this digital divide they belong before pressing ahead

[170] Brian F. Lavoie, *The Open Archival Information System Reference Model: Introductory Guide,* report no. DPC Technology Watch Series Report 04-01, 2004, OAIS Information Model, accessed April 29, 2013, www.dpconline.org/docs/lavoie_OAIS.pdf, 12.
[171] Giovanna Fossati, *From Grain to Pixel: The Archival Life of Film in Transition*, 15.
[172] Giovanna Fossati, *From Grain to Pixel: The Archival Life of Film in Transition*, 15.
[173] Giovanna Fossati, *From Grain to Pixel: The Archival Life of Film in Transition*, 16.

with plans to archive and preserve DCPs and similar digital content for posterity. Defining the scope of an archival collection is a necessary pre-condition for high-level digital preservation because it requires archives to think seriously about their collecting policies with regard to digital content, and to determine whether this policy is in accordance with their institution's mission.

One potential outcome of this process may be that an archive determines that DCPs and other digital content do not fit the institution's remit. This result is important to recognize and wholly acceptable. However if, based on their mission, an archive determines that digital material does fit within the scope of its collecting policy, then it is critical that the appropriate resources and infrastructure required to steward digital objects over the long-term are in place to support this endeavor.

Commit to Becoming a Fully-Fledged Digital Repository

In order for DCPs and related digital audiovisual material to remain accessible to users over a long period of time—the goal of a tenable digital preservation system according to David Rosenthal et al[174]—archives must assume high-level responsibility for this material. This requires a significant amount of resources, organization, infrastructure, and planning across all levels of an organization. Attempting to steward digital material over the long-term on an ad-hoc basis or without the appropriate resources and infrastructure in place is dangerous, and will ultimately put the material at risk. Therefore, it is of paramount importance that archives implement and adhere to standards that have been developed to ensure the long-term viability of digital materials over time.

Reference Model for an Open Archival Information System

Foremost among these is the Reference Model for an Open Archival Information System (OAIS), which was developed by the Consultative Committee for Space Data Systems (CCSDS) and eventually became an ISO standard. In addition to addressing, "a full range of archival information preservation functions including ingest, archival storage, data management, access, and dissemination,"[175] the reference model "identifies a minimum set of responsibilities that must be discharged for an archive to call itself an OAIS archive."[176] Approved in 2002 as an international ISO standard (14721), the OAIS reference model provides a landmark framework that, according to Jean Dryden, "has become the foundation for much digital preservation research and product development."[177]

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[174] David S. H. Rosenthal et al., "Requirements for Digital Preservation Systems," *D-Lib Magazine* 11, no. 11 (November 2005), doi:10.1045/november2005-rosenthal.

[175] Consultative Committee for Space Data Systems, *Reference Model for an Open Archival Information System (OAIS), CCSDS 650.0-M-2,* Magenta Book, Issue 2, June 2012, http://public.ccsds.org/publications/archive/650x0m2.pdf

[176] Donald Sawyer, Lou Reich, David Giaretta, Patrick Mazal, Claude Huc, Michel Nonon-Latapie, and Nestor Peccia, "The Open Archival Information System (OAIS) Reference Model and Its Usage," The Consultative Committee for Space Data Systems (CCSDS), 2002. http://public.ccsds.org/publications/documents/SO2002/SPACEOPS02_P_T5_39.pdf, 6.

[177] Jean Dryden, "The Open Archival Information System Reference Model," *Journal of Archival Organization* 7, no. 4 (2009): 214-17. doi:10.1080/15332740903334116, 216, 216.

The reference model has been designed as "a conceptual framework for systems design, not a blueprint."[178] This allows the model to be interoperable across any number of institutions. In order to be OAIS compliant, an archive must meet six mandatory requirements. These responsibilities as follows:

- Negotiate for and accept appropriate information from information Producers.
- Obtain sufficient control of the information provided to the level needed to ensure Long Term Preservation.
- Determine, either by itself or in conjunction with other parties, which communities should become the Designated Community [user community] and, therefore, should be able to understand the information provided … .
- Ensure that the information to be preserved is Independently Understandable to the Designated Community. In particular, the Designated Community should be able to understand the information without needing special resources such as the assistance of the experts who produced the information.
- Follow documented policies and procedures which ensure that the information is preserved against all reasonable contingencies, including the demise of the Archive, ensuring that it is never deleted unless allowed as part of an approved strategy. There should be no ad-hoc deletions.
- Make the preserved information available to the Designated Community and enable the information to be disseminated as copies of, or as traceable to, the original submitted Data Objects with evidence supporting its Authenticity. [179]

This standard furnishes a translatable model for digital preservation, and provides archives with a useful measure of their institution's commitment to responsible digital preservation vis-à-vis the above criteria. It is strongly recommended that archives implement this standard if they have not done so already, and become compliant with the list of mandatory responsibilities that an OAIS-type archive is expected to meet.

Trustworthy Repositories Audit & Certification

An additional tool that will play an essential role in helping archives to become responsible stewards of digital material is the *Trustworthy Repositories Audit & Certification: Criteria and Checklist* (TRAC). Created as a joint initiative by the Research Libraries Group (RLG) and the National Archives and Records Administration's (NARA) to specifically address

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[178] Jean Dryden, "The Open Archival Information System Reference Model," 216.
[179] Consultative Committee for Space Data Systems, *Reference Model for an Open Archival Information System (OAIS), 3-1.*

digital repository certification, the TRAC criteria formed the basis of the *Audit and Certification of Trustworthy Digital Repositories* ISO standard (16363).[180] Intended, "to be used in combination with the OAIS as a digital preservation planning tool"[181], the documents lay out the organizational and technical infrastructure required for an institution to be considered trustworthy and capable digital repository, and provides a checklist that enables organization to self-audit.

If archives and audiovisual institutions decide that acquiring digital material fits within their remit and define the scope of their collecting policy to reflect this, it is imperative that they take the steps necessary to secure the long-term viability of the digital materials in their custody accordingly. Therefore, it is strongly recommended that archives seeking to preserve digital material over the long-term commit to becoming a fully-fledged, responsible digital repository by implementing the above standards. They are robust, have a high profile, and are widely accepted across a diverse range of disciplines, including audiovisual institutions.

Know the Anatomy of DCPs and Associated Digital Content

DSMs, DCDMs, and DCPs represent distinct points in the mastering process, and differ dramatically in terms of quality, size, and the file formats of the audio and images contained within each element. Consequently, these elements each carry a unique set of preservation concerns, and therefore it is absolutely critical that preservationists have an understanding of the anatomy of these digital files. Without a thorough knowledge of the distinctions between the various elements associated with the production of DCPs, it will be difficult, if not impossible to care for this format in the long-term.

In spite of the fact that this may appear self-evident, in practice, adhering to this recommendation will typically require archives to re-train some members of staff. Mazzanti's article illustrates why this is important for archives by reflecting on how various departments within an institution may be affected by the transition to DCPs:

> Although IT is of course the most critical sector, other parts of the archive must get used to new procedures as digital elements come in or go out: administrators must get used to the fact that 'delivery' might not be 'physical' anymore (they must be told what an FTP is, and this might be a challenge), print loan and distribution will have to deal with DCPs, programming will have to pose new questions besides "Is it 16 or 35?", projectionists must get

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180 Consultative Committee for Space Data Systems, *Audit and Certification of Trustworthy Digital Repositories, CCSDS 652.0-M-1,* Magenta Book, Issue 1, September 2011, http://public.ccsds.org/publications/archive/652x0m1.pdf

181 Consultative Committee for Space Data Systems, *Audit and Certification of Trustworthy Digital Repositories,* 1-2.

> used to the new, menacing and mysterious 'black box' in the booth. And so on.[182]

Although Mazzanti's assessment may seem hyperbolic to larger institutions that already have a robust infrastructure for digital preservation in place, for many archives—particularly those in developing countries that have been slower to convert to digital and typically have fewer resources—DCPs and the infrastructure that surrounds them are less likely to be familiar or accessible.

Mazzanti suggests that although the training required for staff members to make the adjustment to DCPs is easily achievable and not particularly complicated, it will require archives to dedicate time and resources to this endeavor. Moreover, a transitional period will be implied. However a requisite knowledge of DCPs is critical, and it remains the responsibility of the institutions tasked with stewarding this format to ensure that members of staff have the pertinent skills and knowledge required to care for it in the long-term.

Develop Institution-Appropriate Acquisition Policies for DCPs

Because DSMs, DCDMs, and DCPs each require a distinct set of preservation tools and have differing needs with regard to both storage and access, it is crucial for institutions to carefully consider which element or combination thereof will be most appropriate to acquire. Not only will having a sound understanding of a DCP's anatomy allow institutions to better care for the digital cinema elements within their collections, it will also enable them to draft an acquisition policy for digital cinema elements that is designed to meet their specific needs.

Many factors should be taken into consideration before an institution drafts an acquisition policy for DCPs, including its budget, mission statement, and existing digital preservation infrastructure. Because there will be great variation across all of these categories from institution to institution, it is reasonable to expect that there will be considerable differences between their acquisition policies. Evidence of this can be seen above in the distinct preferences of the institutions with whom I spoke for this project.

Do Not Accept Encrypted DCPs

The security protocols established by the DCI are intricate and complex. To date, there are many studios and filmmakers that have expressed a wholesale refusal to furnish archives with unencrypted DCPs, leaving the content creators and those seeking to preserve this content at an impasse. However, it will be impossible for archivists to preserve the files contained within a DCP if they do not have access to them. As Thomas Christensen, Curator at the Danish Film Institute, explains, "encryption should be avoided for preservation

[182] Nicola Mazzanti, "Goodbye, Dawson City, Goodbye: Digital Cinema Technologies from the Archive's Perspective: Part 2," *AMIA Tech Review*April, no. 3 (2011): 9, April 2011, accessed April 10, 2013, http://www.amiatechreview.org/print/volume03.pdf.

elements, since its very purpose is to hinder duplication, which lies at the core of digital preservation activity."[183]

The Library of Congress echoes Christensen's advice in their checklist of factors that will affect the sustainability of digital formats. According to the checklist, technical protection mechanisms—the category under which encryption would fall—represents a substantial danger, making the preservation of a digital file over the long-term an impossible task.

> Content for which a trusted repository takes long-term responsibility must not be protected by technical mechanisms such as encryption, implemented in ways that prevent custodians from taking appropriate steps to preserve the digital content and make it accessible to future generations. No digital format that is inextricably bound to a particular physical carrier is suitable as a format for long-term preservation; nor is an implementation of a digital format that constrains use to a particular device or prevents the establishment of backup procedures and disaster recovery operations expected of a trusted repository.[184]

Finally, it is important to note that the second responsibility that an OAIS-type archive is expected to meet, "emphasizes the need for the OAIS to obtain sufficient intellectual property rights, along with custody of the items, to authorize the procedures necessary to meet preservation objectives."[185] Accepting an encrypted DCP is a clear violation of this responsibility. Therefore, archives should not accept encrypted DCPs because it will not be feasible to preserve them unless they have an agreement (in addition to an appropriate infrastructure) in place through which they can receive and maintain keys for encrypted content.

Recommendations Upon Ingest of a DCP

Under the OAIS model, once an institution-appropriate acquisition policy has been developed and a DCP that fits this policy has been identified, the archive and the content owner will begin the "Ingest" process during which the object and any necessary information will be transferred to the archive for long-term preservation. According to Lavoie,

> Specific functions performed by Ingest includes receipt of information transferred to the OAIS by a Producer; validation that the information received is uncorrupted and complete; transformation of the submitted

[183] Thomas Christensen, "Interview."
[184] Library of Congress, "Sustainability Factors," Sustainability of Digital Formats: Planning for Library of Congress Collections, accessed April 24, 2013. http://www.digitalpreservation.gov/formats/sustain/sustain.shtml.
[185] Brian F. Lavoie, *The Open Archival Information System Reference Model: Introductory Guide,* 4.

> information into a form suitable for storage and management within the archival system; extraction and/or creation of descriptive metadata to support the OAIS's search and retrieval tools and finding aids; and transfer of the submitted information and its associated metadata to the archival store.[186]

The Ingest stage "provides the major interface between the OAIS and the Producer,"[187] and as such it represents one of the most important points in the preservation process. Both the decisions an archive makes about how to handle and store the digital material and the metadata and auxiliary information an archive collects pertaining to the material at this stage can profoundly influence the object's viability over time. There are several actions that an audiovisual institution may take during the Ingest process that will influence both the preservation and access of a digital object over the long-term.

Know the Specification Under Which a DCP Was Made

Just by looking at a DCP, it will be nearly impossible to know with any degree of certainty whether it was produced according to SMPTE or Interop specifications. Given the ubiquity of Interop (as of mid-March 2013, Deluxe, one of the largest DCP manufacturers, reports that they are solely distributing Interop DCPs without a pre-defined end to this practice in sight[188]) it is safe to assume for the time being that most professionally produced DCPs are done so according to the Interop specifications.

However this will change; Whittelsey predicts that the manufacture of SMPTE DCPs could begin to happen as early as "sometime this year."[189] But this change will not take place overnight, and there will be a long period of overlap before the production of Interop DCPs ceases entirely. The side-by-side existence of two distinct specifications will make it crucial for preservationists to know under what specification any given DCP in their collection was produced. Knowing this information may make a significant impact on the how archivists understand this set of files in the future. Therefore, it is recommended that archives include the specification under which a DCP was made as part of the object's preservation metadata in the 'Submission Information Package,' or SIP, which is "the version of the information package that is transferred from the Producer to the OAIS when information is ingested into the archive."[190]

Document and Save Standards

Although knowing under which standard a DCP was made is important, this information is, in and of itself, not useful unless the standards themselves are documented and saved so that members of staff can easily access them in the future. In the OAIS reference model, any information that is deemed "necessary to render and understand" the digital object being

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[186] Brian F. Lavoie, *The Open Archival Information System Reference Model: Introductory Guide,* 6.
[187] Donald Sawyer et al, "The Open Archival Information System (OAIS) Reference Model and Its Usage," 5.
[188] Jim Whittlesey, "MIAP Thesis on DCPs."
[189] Jim Whittlesey, "MIAP Thesis on DCPs."
[190] Brian F. Lavoie, *The Open Archival Information System Reference Model: Introductory Guide,* 11.

preserved is known as "Representation Information."[191] The model requires that the Representation Information be preserved alongside the digital object in question, and notes that Representation Information is crucial to making a digital object available in a form that will be "independently understandable."[192] Therefore, it is recommended that institutions maintain copies of these standards, including any relevant errata, additions, or updated versions, and ensure that staff be able to understand and access this information. These standards will provide a crucial reference for DCPs in the future, and saving and documenting this information will allow preservationists to make use of them in the future.

Migrate the DCP's Content Upon Its Receipt

All hard drives have a limited shelf life. Although estimates vary, commercially produced hard drives are not expected to function properly more than seven years after they were initially produced. In both professional and amateur DCP production environments, hard drives are often re-purposed and reused. It will often be impossible to know how long the hard drive upon which a DCP is received will have been in commission, and whether it has been stored under environmental conditions that may increase the likelihood of its failure. A DCP's files should not be stored permanently on the original hard drive because it will inevitably fail, thus preventing archivists from accessing them.

Moreover, if the DCP's content is not migrated and the sole copy of the material is stored on the original hard drive, it will be impossible to backup and audit this material. All best practices—in addition to the *Audit and Certification of Trustworthy Digital Repositories* and TRAC guidelines—point to the ability to backup and geographically separate digital files as the single most basic criterion of digital preservation. Therefore, it is recommended that upon receiving a DCP, an archive should migrate its files to a secure storage environment as soon as possible.

Although the precise type of storage environment to be used will depend on the institutional context, requirements for access, and infrastructure, a managed, secure environment will include redundancy and geographical separation of backup copies. Not only will this action allow archives to be certain that the files will be accessible in the future, it will be easier to manager storage media migration in the future, and facilitate access to the files.

Once the files have been migrated, quality checked, duplicated, and assigned checksums, the original hard drive should be retained. In spite of their limited shelf life, best practices universally favor keeping the original in case the files need to be migrated or accessed for any reason in the future.

[191] Brian F. Lavoie, *The Open Archival Information System Reference Model: Introductory Guide,* 12.
[192] Brian F. Lavoie, *The Open Archival Information System Reference Model: Introductory Guide,* 12.

Perform Careful, Real-Time Quality Checks

DCPs are complex entities, and there are a number of software applications that exist—both consumer-grade and professional—to facilitate their creation. However not all of these tools are consistent. Errors have been reported in homemade DCPs as well as in those made by professionals. These errors fall into categories that can loosely be defined as those pertaining to content and that affect a DCP's quality. For example, with regard to the former category, Jon Wengström reports that, "sometimes we receive an element that is not up to the standard. [For example,] it doesn't have the color space that we require in our specification, or it doesn't have the right bit-depth, or the sound and image is not in sync."[193]

Errors that fall into the latter category include anything that affects the playback of a DCP. Although their origin remains nebulous, these errors pose a significant threat to DCPs because their presence often renders a DCP's content unplayable. These errors will require vigilance to identify because they can easily pass through a spot check undetected. For Mazzanti, the only solution is to check each DCP in real time. After describing a typical scenario involving a DCP that initially appeared to play correctly but eventually proved to be corrupted, Mazzanti observed that, "if for example, we had checked [the faulty DCP] by jumping through, we might have missed the problem."[194]

Another reason that quality checking every DCP is important has to do with the versioning issues that are often associated with DCPs. It is crucial to verify that a DCP's content is correct when it is first received so that if, for example, a particular set of subtitles are missing, it will still be possible to get the correct set of subtitles from the content's owner. Accessing this material may not always be possible if a versioning issue is discovered several years after a DCP has arrived at an archive, which is why it is recommended that archives perform careful quality checks upon Ingest.

Although this process will consume a significant amount of time and resources, until the software used to create DCPs improves measurably, real-time quality checking represents the only way that preservationists can be certain that the content they have is correct and without error.

Normalize All DCPs Made Under the Interop Standard

Because the Interop standard is so loosely defined, Interop DCPs are not always consistent, and often vary quite significantly from one to the next. It is considerably more difficult to manage a set of files that differ than to manage a set of files that are all alike over the long-term. Therefore, in order for archives to ensure that the DCPs they receive share the same characteristics, it is recommended that institutions normalize all Interop DCPs upon ingest by transcoding and re-wrapping the file's content.

[193] Jon Wengström, "Interview with Jon Wengström."
[194] Nicola Mazzanti, "Interview with Nicola Mazzanti."

For example, the Library of Congress normalizes every DCP they receive because there is no other way they can be certain that the correct profiles of the codecs and wrappers have be implemented. According to Paul Klamer, who heads the video preservation lab at the Library of Congress, as a DCP is ingested, "we would deconstruct that and write it back out to our MXF OP-1a with JPEG 2000 mathematically lossless."[195] This action allows archives to be certain that the files will be optimal for long-term preservation according to their institution's preservation plan.

An important aspect of this recommendation is that the files must be normalized one at a time; batch transcoding is not an option, because it imperils the metadata contained within the original set of files. Therefore, normalizing files must be a boutique procedure that should only occur after the archive carefully examines and records any relevant metadata embedded or wrapped in a set of files and is certain that they understand the implication of the migration process to any relevant metadata.

Use the METS Schema to Encode Relevant Metadata

A DCP is a complex set of digital files. In addition to the image and audio tracks that comprise its essence, a DCP includes additional elements, such as the Composition Playlist, Asset Map, and Volume Index, that each contains a distinct set of metadata. In order to more successfully manage, access, and use these files, preservationists should have a means of retaining structural metadata that describes, anchors, and organizes these components. Therefore, it is recommended that institutions use The Metadata Encoding and Transmission Standard (METS) schema for this purpose.

METS is a metadata standard for encoding descriptive, administrative, technical, and structural metadata pertaining to objects within a digital library. Written in XML, the METS schema is a wrapper that, "allows for metadata, along with all components of a digital object, to be packaged and kept together in a selected storage system."[196] Using METS to generate an XML document that describes the relationships, locations, and purposes of each component within a DCP is an efficient way to manage this information. This allows preservationists to have something akin to a map describing the file, thereby providing a simple way for archivists to look at, understand, and inter-relate a DCP's component parts.

Recommendations Going Forward

After the Ingest process is complete and the appropriate set of associated metadata has been gathered, there remain a number of measures that will be important for archives to take into consideration going forward. These include several initiatives that extend beyond individual institutions to the preservation community at large. Although the issues that these recommendations encompass are not likely to be resolved in the near future, it is

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[195] Paul Klamer and Mike Mashon, "Interview with Mike Mashon and Paul Klamer."

[196] PrestoCentre Foundation, "METS: Metadata Encoding and Transmission Standard," PrestoCentre: Library, Tools, accessed April 20, 2013, https://www.prestocentre.org/library/tools/mets-metadata-encoding-and-transmission-standard.

crucial that the preservation community continue to work toward their solution and engage different communities to help address their resolve.

Be Aware of Hardware and Software Dependencies

As Anne Gant, Head of Restoration, Digital Film and Digital Presentation at the EYE Film Institute explains, one of the greatest challenges to preserving DCPs is the fact that they are "'locked-in' to certain projection technology."[197] Her observation is astute. Not only are DCPs dependent on projection technology for access purposes, specific operating systems—which in turn require particular hardware—are also necessary in order to merely access a DCP's files. It is crucial that institutions understand these dependencies, document this information as part of the digital object's preservation metadata, and prepare accordingly by maintaining the appropriate equipment.

Maintain Technology Necessary to Access Both Linux and Mac Formatted Drives

Although almost all professionally made DCPs are formatted in Linux operating systems, often amateur and independent filmmakers, who are perhaps less familiar with Linux, opt instead to make DCPs on drives formatted in a Mac environment.[198] In order to perform a migration of the DCP's content upon ingest, archives must have access to the appropriate hardware, operating systems, drivers, and any related required software. In addition to facilitating the migration of content off of newer DCPs, having access to this technology may be important should an archive need to return to the original DCP at a later date to migrate the files afresh in light of improved technology. Without access to this technology, accessing and migrating the files that are stored on a DCP will be impossible. Therefore, it is recommended that archives maintain the requisite technology, including hardware, operating systems, drivers, and any related required software, to access both Linux and Mac formatted drives as long as DCPs are still being made.

Maintain Digital Cinema Projection Hardware

In addition to maintaining computer hardware, operating systems, drivers, and related required software, depending on the institution's mission and philosophy surrounding the digital material they collect, it may be necessary to maintain digital cinema projection equipment and xenon lamps[199] in order to be able to accurately replicate the color gamut of that projection technology. As described above, the color gamut of a DLP projector that uses a xenon lamp as a light source is distinct from the color gamut of any other projector model that uses a different light source. Some institutions do not view this change as a problem. Jon Wengström, for example, believes that as long as the Swedish Film Institute has access to the DCDM, that they will be able to "create a viewing copy that will also look

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[197] Anne Gant, "Re: DCP Introduction."

[198] There are many walk-throughs online that feature amateur filmmakers illustrating the process of creating a DCP. Many, including this one, advocate for formatting in a Mac environment. *Getting to Grips with Making a Digital Cinema Package*, dir. Danny Lacey, perf. Danny Lacey, YouTube: Dannylaceyfilm, June 21, 2012, accessed April 18, 2013, http://www.youtube.com/watch?v=5DKYY3DuDA8.

[199] According to *Color and Mastering for Digital Cinema*, "a 5 kW xenon lamp costs approximately $2,000 and must be replaced approximately twice a year." Glenn Kennel, *Color and Mastering for Digital Cinema*, 173.

OK tomorrow" in spite of the differences in the color gamut that would be inherent to newer projection technology.[200]

However, for other institutions, preserving a record of the color gamut inherent to this technology is a priority. According to Mazzanti, being able to reproduce an image as it was originally seen represents the single most important aspect of preserving a film and, moreover, is the defining characteristic that makes the preservation of moving images a unique pursuit from preserving any other kind of digital data.

> The real problem for us, for cinema versus an email, is that we have the look [of a film to consider]. We have to maintain the look and the feel of the images and sound. And that's the tricky part. … Because the objective at the end is not for me to keep the DCP as it is, the objective is for me to, in the future, be able to produce another format that looks [like] the DCP [looked] in 2012. … An archival job is to say, "at the time, this is how film looked."[201]

For Mazzanti, the change in color gamut that will accompany new projection technology represents a significant threat, and will require him to take action. Keeping DLP projectors and xenon lamps in good working order—which may require stockpiling spare parts and manuals—is the only way to preserve a record of the color gamut inherent to this technology. Maintaining this equipment may be difficult, but in Mazzanti's view, doing so will be essential to an accurate understanding how a film would have been seen at the time of its release. Discussing what this will mean for the Belgian Cinematek, Mazzanti says,

> We should theoretically be ready in the future to keep, as we keep a 35mm running in order to compare the 35mm when we do digital restoration to make sure it looks sort of like the 35mm, we should have a 2012 Christie DCP projector and in parallel, a 2025 Windows 22 DCP projector that works on a laser display, and make sure that they look the same.

While other institutions may not agree with Mazzanti's insistence on this point, for Mazzanti, being able to accurately re-create the color gamut of the projection technology for which DCPs are produced is essential. However, saving the digital cinema projectors used to display DCPs is an extremely costly endeavor to which many archives will not have the resources to devote. Moreover, even if archives were not cash-strapped and had budgets that allowed for this task to be accomplished, maintaining this technology may fall well outside the most archives' remit; this task may arguably be one more appropriate to a cinema museum.

Nevertheless, if an institution places a high value on the ability to allow future archivists and curators to see what a DCP looked like at the time of its release and has appropriate resources to devote to this task, it is recommended that current DLP projectors, spare projector parts, manuals, and xenon bulbs be maintained in good working order.

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[200] Jon Wengström, "Interview with Jon Wengström."
[201] Nicola Mazzanti, "Interview with Nicola Mazzanti."

Participate in the Inter-Society Digital Cinema Forum

Although DCPs can be made under a variety of different circumstances using a wide range of tools, all DCPs are made according to a given specification. As the Producer[202] community gradually begins to make the transition from Interop to SMPTE specifications, a number of issues, ranging from technical concerns, to metadata issues, to issues surrounding digital cinema deployment, have become apparent. The Inter-Society Digital Cinema Forum (ISDCF) has emerged as one of the leading organizations to address these concerns, and as such, they are in a unique position to affect the standards that govern the creation of DCPs.

As noted above, the ISDCF is an open discussion forum comprised primarily of individuals involved in some aspect of digital cinema, including participating members from major studios, exhibitors, integrators, equipment manufacturers, and digital cinema consultants.[203] The group's membership is heavily L.A.-centric, and consequently their monthly meetings are held somewhere in the area. Nevertheless, call-in participation is encouraged, and the ISDCF's website clearly states that, "all are welcome to join."[204] According to their website, the ISDCF's mission is,

> 1. To explore all methods of distribution of Digital Cinema Packages (DCP) and Key Delivery Messages (KDM) to theaters worldwide; to recommend technologies within each class of distribution for common acceptable solutions; and to provide information regarding these technologies to the Digital Cinema community.
> 2. To provide an information exchange resource for the digital cinema roll-out.[205]

Recent subjects of discussion have included KDM delivery, subtitles, captions, closed captions, SMPTE specifications for digital audio, and issues surrounding the formatting of distribution hard disc drives. Many of the issues that the ISDCF chooses to address arise out of gaps, weaknesses, or vagueness in the existing specifications. Their recommendations are taken seriously and are frequently adopted by the Producer community, which in turn influences the revision of the existing SMPTE standard. Whittlesey summarizes the reach of the ISDCF's influence by noting that "everyone in the distribution food chain" pays attention to the recommendations that they draft, noting that their recommendations matter precisely because they have the ability to affect how DCPs are understood and manufactured.[206]

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[202] The Producer is defined in the OAIS reference model as, "the individuals, organizations, or systems that transfer information to the OAIS for long-term preservation." Brian F. Lavoie, *The Open Archival Information System Reference Model: Introductory Guide,* 6.

[203] Inter-Society Digital Cinema Forum, "Welcome to the ISDCF!," Inter-Society Digital Cinema Forum (ISDCF) Discussion Group, accessed May 5, 2013, http://www.isdcf.com/old/ISDCF_Public/Public_Home.html.

[204] Inter-Society Digital Cinema Forum, "Welcome to the ISDCF!"

[205] Inter-Society Digital Cinema Forum, "Welcome to the ISDCF!," Inter-Society Digital Cinema Forum (ISDCF) Discussion Group, Mission Statement, accessed May 5, 2013, http://www.isdcf.com/old/ISDCF_Public/Public_Home.html.

[206] Whittlesey, Jim. "More Questions for Jim Whittlesey."

As the SMPTE specification gradually becomes more prominent within the Producer community, it will be important for preservationists to not only be privy to the conversations that arise around this specification, but to become active participants. Thus, it is recommended that preservationists take advantage of the ISDCF's open forum and engage in their discussions, either by taking part in the ISDCF's monthly meetings or by remaining informed vis-à-vis the ISDCF's listserv. The latter is a particularly rich source of information that provides valuable insight into the conversations that are shaping digital cinema. By becoming active participants in these discussions, preservationists will ultimately be in a better position to help steward digital material, and may even be able to influenced by the ISDCF's recommendations.

Support the Development of Open Source Tools that Implement the Full JPEG 2000 Specifications

JPEG 2000 is extremely complex. Although there are many applications and tools that support JPEG 2000, many of these do not support the full JPEG 2000 specification. As a result, interoperability issues can arise when one vendor or institution implement differing interpretations of the same standard. However, as Jim Lindner puts it, "You can't force companies to be 'compatible' just because you want it to be so. The best way to get what you want is to buy stuff, or convince Open Source groups that what you want is important so that they should support it."[207] Therefore, it is important for the preservation community to engage and work with developers of open source tools to improve their spectrum of support for JPEG 2000. Although this recommendation does not address some of the extant concerns surrounding the format, including its niche adoption and its complexity, an open source tool that recognized and supported the full JPEG 2000 specification would help address the problem of interoperability. This would be useful to both vendors and audiovisual archives alike and would measurably improving the prospects of DCPs in the long-term.

Engage With Studios to Address the Problem Posed By Encryption

To date, studios have expressed an extreme reluctance to allow unencrypted digital content outside of their control. This has resulted in a stalemate between archives and the studios that has, in certain cases, threatened to upend the missions of audiovisual institutions whose collections have traditionally included content generated by the studios. In spite of this apparent impasse, it is crucial that the preservation community engage with studios to find a solution that addresses the issue of encryption and offers the possibility of satisfying both parties. Although this may seem unlikely given the current stalemate in which studios and archives find themselves, there are several solutions that may offer some feasible, albeit in some cases improbably, possibilities.

The first possibility is a scenario in which the studio or filmmaker provides an archive with an encrypted DCP and either places the KDM in escrow for a certain amount of time.

[207] Jim Lindner, "Re: Research Suupporting Jpeg2000 True Mathematical Lossless Compression."

Alternatively, the encryption that is applied to the DCP could be scheduled to simply expire after a given period of time. This would allow the DCP's content to remain secure until, for example, either a film's theatrical release date and/or the date at which the film became available on consumer formats had passed. The archive would be able to access the KDM after the appointed date, which would provide the archive with the keys necessary to unlock the DCP and ingest its content into the collection.

This strategy could theoretically allow the industry to maintain tight control over a film during the year following its initial release when it stands to make the greatest profit. By providing a KDM only after a film had made the lion's share of its profit, a film's owners could ensure that providing an unencrypted DCP would not put the film at a great risk even if its contents were compromised. However, this solution is not without flaw. If the DCP is encrypted for an extended period of time, both the DCP's hardware and potentially the hardware upon which the DCP is dependent to play (ie, a digital projector) are likely to become obsolete. Therefore, this strategy could only work within a time frame of several years or less. However another problem inherent to this strategy is that while it may work well for a studio with large staff capable of managing the date keys to encrypted DCPs, this model works less well for independent filmmakers that do not have the time or resources to manage the keys.

A slight variation on this approach that would not require either studios or filmmakers themselves to manage keys over time would be for the film's owners to create two sets of keys for every DCP—one that would be permanent, and another that would constantly change. Generating two sets of keys can be easily done using any asymmetrical encryption strategy including the RSA encryption model that is already in place for DCPs. This would allow an archive to receive a permanent key that would allow unfettered access to the DCP's content, while exhibitors would continue to receive time-limited keys.

Another strategy is one put forth by David Bordwell, who posits a reversal of the key management system altogether. Bordwell suggests that an archive could be given an unencrypted DCP, and could then generate its own key to prevent the DCP's content from being pirated.[208] However because filmmakers and studios thus far have been wholly unwilling to send out unencrypted DCPs, a slight modification of this model might entail a film's owner sending out an encrypted DCP, providing the archive with a KDM, and then allowing the archive to ingest the files into its collection under the condition that they then re-encrypt the files.

This model would result in archives taking on the responsibility of key management for the digital cinema within their collection, and would thus shift the onus the protecting a DCP's content from the film's owner to the archive. However, this would require a film's owner to essentially cede control over the DCP on deposit. For a film's owner to give up control over a release print of an analog film or video recording was standard. However thus far, filmmakers and studios have been adamant about retaining strict control over their

[208] David Bordwell, *Pandora's Digital Box: Films, Files, and the Future of Movies*, 183.

intellectual property. Therefore, this model seems unlikely to be adopted as-is given the current climate of fear surrounding piracy.

A solution that would take a slightly different approach centers on borrowing a model for data security developed on behalf of the health industry in the 1990s. Like newly released feature films, health data is considered extremely sensitive; a breach in security could carry significant consequences. The Health Insurance Portability and Accountability Act (HIPAA) of 1996 addressed the security and privacy of health data, and one of its mandates compels organizations that store health data to be certified as HIPAA compliant by meeting a minimum number of security requirements. Therefore, any storage facility seeking to protect health data must undergo a strict process of review that is regulated by an outside body.

Using the HIPAA system as a model, archives could undergo a standardized certification procedure wherein their security systems would be routinely inspected by a regulating body. This neutral third party would be responsible both for setting security standards and for certifying the archive as being compliant with those standards. This model would benefit the owner of a film, who could be satisfied that their material would be safe. Furthermore, this model would be advantageous for archives, which would be able to use the periodic security review to their benefit as a means of ensuring funders and filmmakers alike that their collections were safe and secure.

In fact, there is already a precedent for this solution within the film industry itself. In addition to publishing best practices for security,[209] since 2008 the Motion Picture Association of America (MPAA) has had a review process for ensuring the security of post-production and production facilities both in Hollywood and throughout the world. According to their website, "these reviews were performed using a standardized survey model, process and report. Since then, over 400 facilities have been inspected in 35 countries."[210]

There is also a precedent for this model within the archives community. In the United Kingdom, a trade organization called The Federation Against Copyright Theft (FACT) certifies businesses to ensure that their premises are secure. According to FACT's website, "Businesses wishing to provide services to the audio-visual industry must satisfy members they have sufficiently high levels of security in order to safeguard the intellectual property rights of FACT members."[211] So far this security review procedure has worked well in the U.K. According to Helen Edmunds, the Collections Manager at the British Film Institute, this

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[209] Motion Picture Association of America, "Content Security Best Practices: Common Guidelines Version 2.0," Motion Picture Association of America, May 15, 2011, accessed May 6, 2013, http://www.fightfilmtheft.org/docs/CG.pdf.

[210] Motion Picture Association of America, "MPAA Facility Security Program," MPAA Facility Security Program: Fight Film Theft, Objective, accessed May 06, 2013, http://www.fightfilmtheft.org/facility-security-program.html.

[211] The Federation Against Copyright Theft, "About FACT," FACT, 2012, accessed May 06, 2013, http://www.fact-uk.org.uk/about/.

system has enabled the delivery of some unencrypted DCPs to the BFI in advance of their theatrical release dates.[212]

Given the precedent that already exists for this model, a regulated security procedure appears to be the most viable solution at present. However while this model holds potential, the challenge would lie in creating security measures strong and credible enough to convince filmmakers and studios that their intellectual property would be safe within an approved facility.[213] In spite of the MPAA's efforts to achieve this outcome for post-production houses, these facilities are still the leading sources of pirated pre-release material.[214]

Although encryption poses a significant challenge to archives, it is important to note that DCPs have broader archival concerns inherent to the format that extend beyond its security. As Novak observes, even if an archive has access to a KDM, a KDM for a specific server-projector system is of very limited use to an archive, because the only possible use for the files would be playback on the given server-projector combination dictated by the KDM. If either the server or the projector ever needs to be replaced—which is likely given the rapid changes occurring within the realm of digital cinema—the KDM becomes invalid.[215]

VIII. Conclusion

The recent shift toward digital technology has begun to steadily transform film archives and audiovisual institutions. This transition has the potential to profoundly affect the way that film is collected, seen, accessed, and understood in an archival setting. However these changes bear consequences. Archives must carefully consider what their roles will be with regard to collecting and preserving digital material. A number of factors may contribute to this decision, including the institution's mission, available resources, existing infrastructure, and facilities for access. Benign neglect is not an option; digital material requires active and continual stewardship in order to be preserved and made accessible over time, and archives must consider whether it is appropriate to take on the stewardship of this material in light of its stringent requirements.

This necessitates that archives carefully consider what their roles vis-à-vis this material will be in the future, and question the principals and theoretical frameworks that guide

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[212] Helen Edmunds, "Archiving and Preserving Digital Cinema Packages," Presentation, Association of Moving Image Archivists Conference, Seattle, December 6, 2012.

[213] Although archives typically receive a film long after its initial release, thus making the threat of piracy from within the archive perhaps a diminished concern, the studios are skittish about piracy and regard any form of piracy a substantial threat to their bottom line, regardless of when it occurs in relation to a film's release date.

[214] Matthew Belloni, "'X-Men: Wolverine' Pirate Sentenced to Year in Federal Prison."

[215] Arne Nowak, "Digital Cinema Technologies from the Archive's Perspective," 12.

their archival philosophy. For example, does the archive understand “film” to be inclusive of digital objects? How is the notion of the “original” complicated by the reproducibility of the digital medium? Is the institution’s ultimate goal to be able to re-create the experience of seeing a DCP in the future when the technology has advanced? To provide basic level of access to the DCP’s content? Or to maintain the highest quality version of the material that is available?

All of these questions bear consequences with regard to an archive’s collecting policies and its plans for access. Archives must have a clear vision of what their purpose for collecting this material will be, and must consider whether or not they will be able to facilitate this responsibility given the technological, financial, and organizational restraints that may be involved.

If an archive does make the determination that it fits within their mission to collect DCPs specifically and associated digital material more broadly, then it is essential that the requisite funding, infrastructure, and skill sets are in place to support this mission. This includes a high-level digital preservation plan that relies on robust, widely adopted standards, and the training necessary to carry out this preservation plan. It is likely that even the most well funded, trained, and equipped archives will have to implement a series of changes in order to accomplish this, but if they do not, the archive will effectively put at risk the material they are tasked with safeguarding.

DCPs are complex entities that entail a number of risks with regard to their long-term preservation, and will require active and continual stewardship in order to be preserved and made accessible over time. Some of these risks, such as the concerns surrounding JPEG 2000 and MXF, the vulnerability of hard drives, and the rapid rate of change inherent to digital cinema technology, are endemic to other areas of digital preservation, and therefore are already well known to preservationists. But others, including the existence of two competing and sometimes incompatible specifications, the use of encryption, issues surrounding DCPs’ formatting, difficult to identify bugs and kinks inherent to the software used to create DCPs, and concerns surrounding the color gamut that is specific to the projection technology to which DCPs are ‘locked-in,’ are unique to the format, and will require a long-term commitment on the part of the preservation community to address.

While the above risks make caring for this material a significant responsibility, preserving DCPs *is* possible. Nevertheless, this is only feasible if a concerted effort is made to understand the format and examine its associated risks in some depth, and it is my hope that the research presented here will be a step in that direction.

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