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# Digital Cinema Technologies from the Archive's Perspective

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## 1 Introduction

During the last few years digital technologies have gained much ground in production, editing, post- production and exhibition of cinematographic work. This fundamental change of technologies also has had a large impact on archives. On the one hand archives have very successfully implemented digital restoration and digital distribution of films on the internet or via DVDs, as well as to digital cinemas. On the other hand archives will have to adapt and change existing procedures or introduce new processes because they will be confronted with digital material for deposit that is not bound to a carrier medium, as is the case with film or video cassettes. Instead the images and sound will come to the archives in the form of digital computer files.

Digital cinema has evolved over the last few years, and even though various alternative systems and solutions are used in different parts of the world, most commercial productions in North America and Europe use a system that has its origin in the Digital Cinema Initiatives[3] (DCI). DCI was a joint venture of six major American film production companies which together worked out an open specification for a digital cinema system. Many parts of this specification have been adopted by SMPTE and also transformed into standards by the international standardization organization ISO.

This article is intended to give a basic introduction to the technologies and processes that are associated with the DCI / SMPTE digital cinema system. In the following sections I give an overview of the basic technologies that are used, describe important technical details of the Digital Cinema Package (the format that is delivered to the cinemas), point out how these packages can be produced and give some thoughts on implications of this system on archives.

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# 2 Basic technologies and standards

The digital cinema system as it is used today in North America and Europe is defined by a set of SMPTE standards which are mostly based on the voluntary specification of the DCI. Currently, SMPTE standard documents exist and are effective for all essential parts of the systems. Ongoing work in standardization is mostly concerned with additional features and extensions such as the recently released additional frame rates document that introduces the possibility of other frame rates than the originally specified 24 and 48 FPS[4] as well as archive frame rates[5]. Many of the SMPTE standards for digital cinema also have been adopted by the ISO in its technical committee TC36[6].

The SMPTE standards take care of different important technical aspects of digital cinema. A complete list can be found at http://www.smpte.org/standards. The documents describe the D-Cinema Distribution Master (DCDM, SMPTE 428), D-Cinema Packaging (DCP, SMPTE 429), D-Cinema operations (including key management for encrypted packages, SMPTE 430) and D-Cinema quality for projection (SMPTE 431). All of these documents contain references to other standards from SMPTE, ISO and other organizations that describe certain technical details, and there exist also several SMPTE Recommended Practice documents for D-Cinema. The DCI Digital Cinema System Specification, which is available for download free of charge at http://www.dcimovies.com, contains detailed descriptions of the technical aspects and serves as a good reference, since huge parts of this specification have been included in the SMPTE standards. The DCI Specification additionally contains very detailed information about all encryption and content security related aspects and serves as the operational guideline for the studios that are involved in the DCI.

All technologies that are used within the SMPTE / DCI D-Cinema system are openly available and can be used free of license or patent fees of any kind by all interested parties. This allows any person, company or organization to develop systems or software that comply with these standards. In fact, besides several commercial solutions to create Digital Cinema Packages (DCP), at least one free open source software implementation exists to do this.

The SMPTE / DCI D-Cinema system is centred on the DCP. This is the compressed format in which digital movies are delivered to the cinema and from which they are projected. D-Cinema is essentially a file and IT-oriented environment. The DCP is a set of files that contain images, sound, subtitles and additional files to control playback and optional encryption of the content. Images and sound are stored in separate files that are called track files and there is the possibility to divide a movie into several reels. That means the complete set of images and sound data and also subtitles are split into several files of arbitrary duration. The playback order is controlled by a Composition Playlist (CPL) that includes references to the image, sound and subtitle files. A DCP can contain more than one CPL. This makes it possible, for example, to create a multi-language DCP that contains only one set of image track files that are used for all language versions but several sets of sound track files, one for each language. Each CPL now contains references to the shared image track files and the sound track files for each language.

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[4] SMPTE, ST 428-11:2099, SMPTE ST 428-19:2010
[5] SMPTE ST 428-21:2011
[6] http://www.iso.org/iso/iso_technical_committee?commid=48090

The following sections of this article give explanations of the technical details of a DCP, including encryption and access control, the mastering and creation of DCPs, and discuss the relevance of DCPs in film archives and implications related to their use as a deposit, exhibition and distribution format.

# 3 The Digital Cinema Package

## 3.1 Overview

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. The format takes a relatively simple approach to realize the required features. A DCP is essentially a folder on your hard disk that contains a set of MXF and XML files.

MXF stands for Material eXchange Format and is a so-called wrapper or container format similar to Quicktime .mov or Windows .avi files. MXF was developed by SMPTE and EBU for use in professional TV applications and is a very powerful but unfortunately also complex format. It can be used to store image or sound data (also called essence) and metadata. MXF itself is codec agnostic, which means that an MXF file can contain images or sound compressed using various systems or even uncompressed image and sound data in a single common file format. A simple internal MXF file structure and the wrapping process are depicted in Figure 1. The resulting MXF file on the right consists of a file header with metadata and the file body that contains the essence. In the DCP only very simple MXF files are used. These so-called "Operational Pattern Atom" files store either images or (multi-channel) sound data in each file. Only very rudimentary metadata is supported in the MXF files of a DCP. To reduce storage space and speed up transmission of DCPs the images are compressed using the JPEG 2000 codec, but at a very high quality level. Sound is stored uncompressed. Subtitles can either be stored as XML files that contain timed text or as subpictures. Timed text means that the subtitle texts are stored together with a time code that controls when the text appears on the screen in an XML file. The text is rendered and combined with the image in the projection system. A subpicture is pre-rendered image of the subtitles with transparency that is combined with the images of the movie at playback time. In this case the timing is also controlled by an XML file.

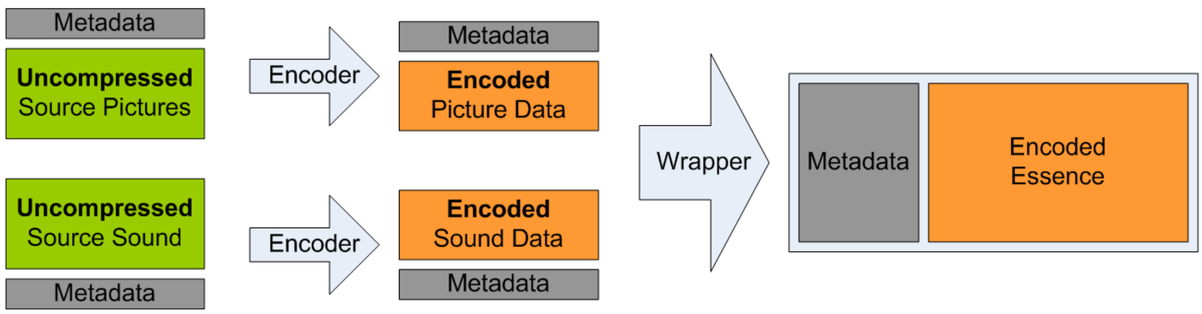


**Figure 1 - Wrapping of images, sound and metadata into a single file**

In addition to the files that contain the essence, several other XML files are contained in the DCP. The most important ones are the Packing List (PKL) that contains an inventory of all files that belong to the DCP and one or more Composition Playlists (CPL) that control playback of the essence in a DCP. The file names can in theory be arbitrarily chosen since all files are, during playback, referenced using internal identifiers (the so-called UUID) and not the file names. Figure 2 gives a simple example for a movie trailer with one MXF file for audio and one MXF file for the images.

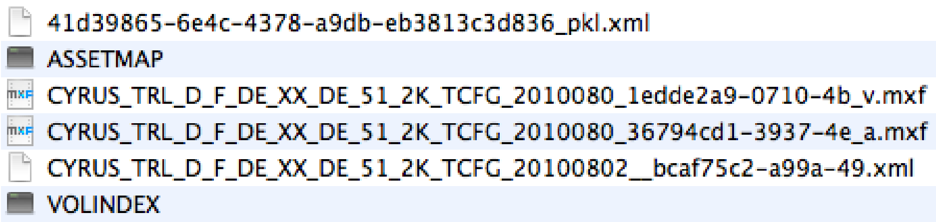


**Figure 2 – Files in a Digital Cinema Package**

## 3.2 Images and sound

One of the goals of D-Cinema standardisation was and is to ensure a high level of image and sound quality. This goal is reflected in the technical details of the standards such as image compression, spatial resolution and colour fidelity.

In the standards two basic resolution containers are defined: 2K with 2048 x 1080 pixels and 4K with 4096 x 2160 pixels. Of course only a small number of movies are intended to be shown at the native aspect ratio of these containers which is 1.896:1. For other aspect ratios the resolution shall extend to the maximum of either the horizontal or the vertical resolution. In practice this means that a movie with an aspect ratio of 2.39 in a 4K container shall have an image resolution for the active pixels of 4096 x 1716, therefore filling the horizontal resolution of the container. It should be noted that the use of anamorphic projection lenses is explicitly not permitted in the standards which leads to the consequence that a CinemaScope movie may have a lower overall spatial resolution than other aspect ratios.

The primary frame rates that are supported by SMPTE / DCI D-Cinema systems are 24 FPS and 48 FPS. However, the standards have been extended[7] to support additionally 25, 30, 50 and 60 FPS. As archive frame rates, 16, 200/11(≈18), 20 and 240/11(≈22) FPS are supported in the standard[8]. Other frame rates may follow but the basic requirement for D-Cinema equipment is to support 24 FPS and 48 FPS. So not all installed playback servers and projectors will be able to play at the extended frame rates and there is currently not much software or equipment available that supports the creation or playback of archive frame rate DCPs. As of 2012 there is an intense discussion going on towards using higher frame rates, especially for stereoscopic DCPs[9].

The images are stored in the XYZ colour space using 12 bits per component and per pixel and a gamma correction value of 2.6. XYZ is a device-independent colour space that includes all possible colours in the visible spectrum. This makes it future proof in the sense that no changes to the format are necessary with the advance of technology in

[7] see SMPTE ST 428-11:2009
[8] see SMPTE ST 428-21:2011
[9] „A White Paper on High Frame Rates from the EDCF Technical Support Group“ by Peter Wilson, European Digital Cinema Forum. January 2012. http://www.edcf.net/edcf_docs/White%20paper%20on%20High%20Frame%20Rates%20Final%2009012012.pdf

recording and projection. Since all projectors work in the RGB colour space, a conversion has to take place during projection. The standards also define a minimum RGB colour space for the projectors and include specifications for colour accuracy and screen luminance.

At its original maximum resolution and 12 bits per component a single uncompressed 4K image needs roughly 39.8 Mbytes of storage space. This translates to a data rate at 24 FPS of 955.5 Mbyte/s or 7.6 Gbit/s[10]. Since this amount of data is too high to be handled in distribution to and projection in the cinemas, compression has to be applied. Because natural images usually contain a fair amount of redundancy and also because the human visual system only has a limited sensitivity for certain image details, digital image compression can be applied to a certain degree without leading to a visible loss in quality for the audience. In the SMPTE D-Cinema system the JPEG 2000[11] compression algorithm is used for image compression. It is an intra-frame compression, which means that each image is compressed without looking at preceding images. JPEG 2000 is especially suitable for large resolutions at relatively high data rates and includes scalability features that are used in D-Cinema to simultaneously store 2K and 4K images in a single file. Simplified, a 4K image contains a 2K image plus the differences between the 2K and the 4K image. During playback of a 4K DCP a 2K projection system only reads and decompresses the 2K part of the compressed image and ignores the additional information for the 4K part. It is also possible to create 2K-only DCPs, and all playback server and projection systems, no matter if 2K or 4K, are required to support the playback of both 2K *and* 4K DCPs.

The maximum allowed data rate for the JPEG 2000 images in a DCP is 250 Mbit/s for both 2K and 4K DCPs. Practical experience shows that for natural images in the case of a 4K DCP only a relatively small percentage of the overall data rate is used to store the resolution difference between 2K and 4K. To achieve this data rate JPEG 2000 has to be used in its lossy compression mode. This means that image information is irretrievably lost during compression, but this happens in a way that the difference is usually unperceivable for a human viewer. If the data rate is set too low the images will first become blurry before more annoying compression artifacts become visible. Since JPEG 2000 does not use a block structure like MPEG-2 no blocking artifacts will occur. The critical data rate at which artifacts become visible strongly depends on the nature and technical details of the source images. In practice, data rates between 80 Mbit/s and 150 Mbit/s usually lead to acceptable results and often data rates significantly lower than the maximum of 250 Mbit/s are used to save storage space. At the maximum data rate of 250 Mbit/s a one hour movie would result in a DCP of around 115 GBytes in size. In a DCP JPEG 2000 compression is normally applied using variable bit rates for each frame. This means that images with little detail – such as those that contain the closing titles on a black background – are compressed to very small files, while images with lots of fine details result in files as big as the maximum allowed size even if the average data rate of the complete movie is well below this limit.

On a side note, JPEG 2000 also supports a mathematically lossless compression mode that makes it possible to recreate the original image without any loss of information. This is not used in the DCP but may be useful for archiving high quality material.

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[10] All data rates are given in power-of-ten units.
[11] see ISO/IEC 15444-1:2004 and ISO/IEC 15444-1:2004/Amd 1:2006, http://www.iso.org/iso/catalogue_detail.htm?csnumber=37674

Since a movie usually consists of several tens of thousands of single images, storing each compressed image in a single file on the hard disk would be complicated to handle and impose additional file management overhead. The solution is to put all image files into a so-called container or wrapper format. In the DCP the Material eXchange Format MXF is used for this purpose. An MXF file consists of a header section that in a DCP mostly contains technical details of the images and a body section that contains all images. In a DCP, sound and images are stored in separate MXF files.

Sound data is generally stored uncompressed in a DCP and is also wrapped in MXF files. One sound track file can contain up to 16 discrete channels of audio which are typically used for multi-channel audio formats. Sound is sampled at 48 kHz or 96 kHz with 24 bits per sample. To handle multiple languages usually one sound track file exists per language, each of which can contain multi-channel audio data. Which sound track file and therefore which language is played is controlled by the Composition Playlist.

## 3.3 The package

The Digital Cinema Package is the entirety of all image, sound and subtitle track files, Composition Playlists, a Packing List, an Asset Map and an optional VolumeIndex. The functions of the track files have been discussed in the previous sections.

The Composition Playlist (CPL)[12] is a "self-contained representation of a single complete D-Cinema work, such as a motion picture, or a trailer, or an advertisement, etc."[13] It specifies in which combination and order the assets (image, sound and subtitle track files) are played back to form this D-Cinema work. A DCP can contain more than one CPL and each track file can be referenced by more than one CPL. This makes it possible to create multi-language versions that reference the same picture track files but different sound or subtitle track files. It is even possible to create multi-language versions where some parts of the image differ for each language. To accomplish this it is necessary to put the differing scenes in separate image track files that can then be addressed by the appropriate CPL. Figure 3 gives a principle overview of the relations between CPL and track files.

The Packing List (PKL)[14] is an XML file that contains information about all files that belong to a DCP. The Packing 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. Hash values or checksums are numbers of a certain length that are calculated from a file that is to be hashed and that can be used to identify manipulations or transmission errors. A playback server should recalculate the hash values from the asset files and compare them to those in the Package List to ensure the integrity of the package.

The Asset Map[15] describes the location of each asset on the storage media. It contains for each asset an entry that maps the UUID of the asset to a path on a file system. It is also possible to split assets that are too big for one single storage medium. In that case the asset map contains information of where to find all the chunks of one file on a

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[12] see SMPTE ST 429-7:2006
[13] from SMPTE ST 429-7:2006, section 3
[14] see SMPTE ST 429-8:2007
[15] see SMPTE ST 429-9:2007

multi-volume set of storage media. In that case the VolumeIndex[16] shall be used to identify each volume.

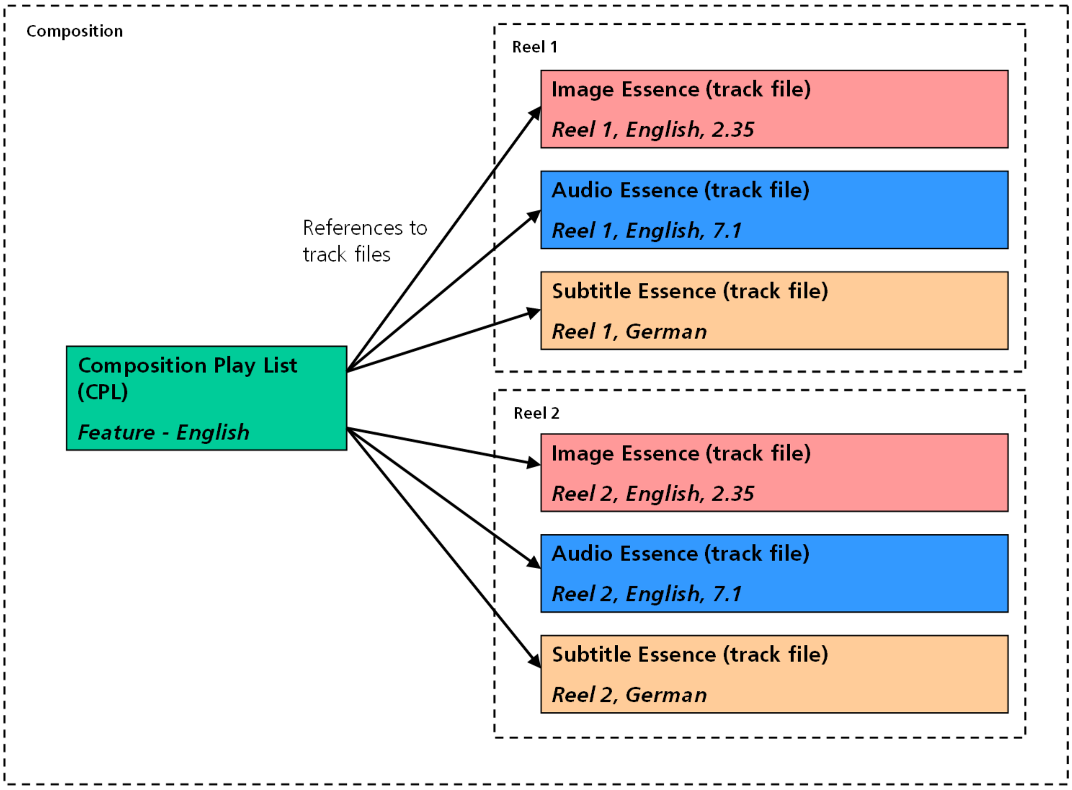


**Figure 3- Relation between CPL and track files**

## 3.4 Encryption and access control

Encryption of a DCP is an optional possibility, but one that is used for most commercially distributed movies in order to enforce access control for the content. The DCI Specification contains many details of the complete access control and content security concept that encompasses encryption of the file in a DCP as well as mechanisms to ensure that only authorized playback systems are able to decrypt the content. The Specification also takes care of measures to prevent and detect manipulations of the playback systems. In this section of the discussion we will focus on the encryption and key delivery mechanism because this is the most important part for content producers and archives that receive encrypted DCPs.

The encryption-based content security and access control mechanism consists of two separate parts that are important here: 1) The encryption of the track files including digital signatures to ensure the authenticity of the CPLs and PKL and 2) The mechanism to deliver the cryptographic keys that were used to encrypt the track files to the playback system to enable the decryption and projection of the DCP. The encryption systems and algorithms that are used are standardized and have been commonly employed in information technology, encrypted emails, other documents and data for many years.

[16] see SMPTE ST 429-9:2007

MXF track file essence encryption[17] makes use of the AES[18] system with 128-bit keys. AES is a symmetric encryption system, in which a single key is used both to encrypt and to decrypt a file. This means of course that if someone has the key that was used to encrypt a file he can also use it to decrypt the file. The conclusion is that the AES keys have to be kept secret and they should only be made available to the playback server systems that are authorized to decrypt and playback a DCP. Normally, the only point where these AES keys exist in plaintext is during production of an encrypted DCP. In a DCP each MXF track file shall be encrypted with its own key and with only one key per MXF track file.

Since the AES keys have to be kept secret they must be encrypted themselves before their transmission to the cinemas and to the D-Cinema playback servers. This is accomplished by using a second, substantially different cryptographic algorithm called the RSA public key algorithm[19]. This is an asymmetric system. That means that a pair of two different keys is used: the receiver of an encrypted message holds a private key that must be kept secret and that is used to decrypt an encrypted message. The second key in the pair is the public key that is only used to encrypt a message but cannot be used to decrypt it again. This asymmetric system makes it possible to send an encrypted message to a receiver without the necessity to arrange the secure exchange of a secret key.

In the case of a D-Cinema playback server the asymmetric key pair is created by the manufacturer of the server during production of the device. The private key is stored tamper-proof in a special hardware part of the server and there shall be mechanisms in place that ensure that the secret private key is automatically erased if someone tries to manipulate the system in any way. This means that not even the owner of such a server has the possibility of retrieving this private key. On the other hand, the public key that belongs to the private key of a playback server is available from the manufacturer or delivered together with the server, and this key is used to create Key Delivery Messages (KDM[20]) for DCPs that are specific for this server and that in turn contain the now RSA-encrypted, secret AES keys that were used to encrypt a DCP.

A KDM can contain the keys for one or more playback servers. It is also possible that a KDM might only contain the keys for one language version of a multi-language DCP while you would need another KDM to be able to playback another language. KDMs may also contain restrictions that define the time during which a DCP can be played back. In theory an end point very far in the future is possible. Additionally, hashing and signature mechanisms are in place to ensure authenticity of a KDM and to prevent manipulation of KDMs during delivery to the cinema. Figure 4 gives an overview of the encryption, key delivery and decryption process.

The advantage of this two-stage approach is that a DCP only has to be encrypted once and not individually per cinema or per playback server. The connection to the playback servers is only established at the point where a KDM is created. Since each AES key has a size of 128 bits the size of a KDM usually is only a few kilobytes. Therefore a KDM can

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[17] see SMPTE ST 429-6:2006
[18] Advanced Encryption Standard (FIPS 197), http://csrc.nist.gov/publications/fips/fips197/fips-197.pdf
[19] see “PKCS #1: RSA Cryptography Specifications Version 2.1” By B. Kaliski. February 2003. RFC 3447, http://www.ietf.org/rfc/rfc3447.txt
[20] see SMPTE ST 430-1:2006

be easily and quickly created and also transmission of the KDM to the cinema can be achieved via email or small USB memory sticks.

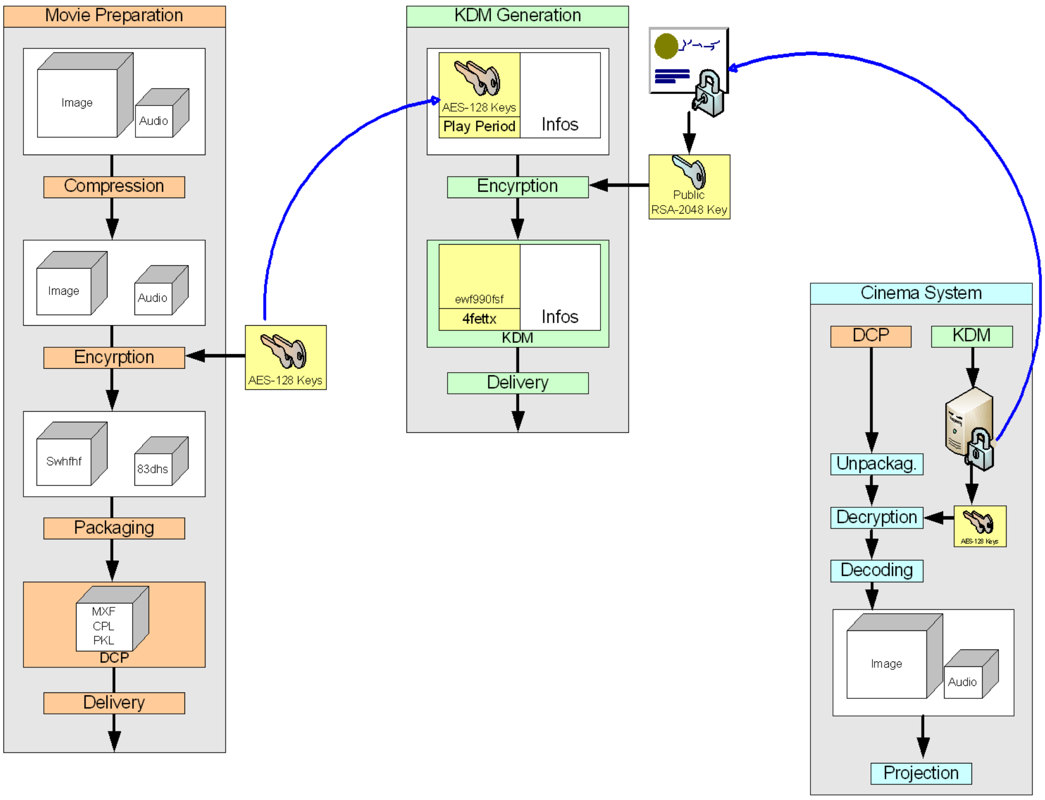


**Figure 4 - DCP and KDM encryption process**[21]

# 4 Producing a DCP from an archive film

The production of DCP is a straightforward process that can somehow be compared to producing a video DVD. It usually consists of several steps:

1) Preparing the images, sound and subtitles;
2) Importing everything into the DCP authoring application;
3) Arranging the material in compositions that form the CPLs and setting general parameters; and finally
4) Starting the process to convert and compress, optionally encrypt, the images and sound data, create the MXF and XML files.

The result is a folder on a hard disk that contains the DCP and that can be copied to other media for transfer to the cinema.

Systems to create DCPs are available from different vendors like Doremi[22], Dolby[23], Fraunhofer IIS[24] or the open-source Open Cinema Tools[25]. The software-only solutions

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[21] see "System specifications for digital cinema in Germany V1.02", Fraunhofer IIS, 2008
[22] see http://www.doremilabs.com/products/cinema-products/
[23] see http://www.dolby.com/us/en/professional/hardware/cinema/postproduction-products/scc2000.html
[24] see http://www.iis.fraunhofer.de/en/bf/bsy/produkte/easydcp/, http://www.iis.fraunhofer.de/en/bf/bsy/produkte/curator/
[25] see http://www.opencinematools.org/

from Fraunhofer IIS and the Open Cinema Tools run on any standard PC or Mac. However, it is advisable to use a fast multi-processor, multi-core computer with a fast and large hard disk system because JPEG 2000 encoding is a very complex process and the source image files will be in most cases very large.

Most systems accept TIFF and DPX files as input for images and WAV files for the soundtrack. Most of the time it is not necessary to explicitly create the D-Cinema Distribution Master[26] (DCDM) that is mentioned in several SMPTE standards and is described as 16 bit TIFF files for images. The necessary conversion steps, like colour space transformation to XYZ or scaling of the images, are often carried out during the encoding process and some systems even accept Quicktime .mov files as input formats.

In the case of creating an encrypted DCP, there are two basic possibilities: images and sound can be encrypted during the encoding and MXF wrapping process, or an unencrypted DCP can be created that is encrypted at a later stage. In both cases the authoring or encryption systems provide means to store the AES encryption keys for later use to create KDMs for the playback servers. The KDMs are typically created by an additional software system.

To create a DCP from an archive film the starting point are in most cases scanned and colour graded DPX sequences and the final audio mix as WAV or AIFF files. At first, the reel boundaries for the DCP have to be determined. In order to make data handling easier the DPX files should be moved or copied into one separate folder on the hard disk per reel. Now the audio files have to be cut, also according to the reel boundaries. The result is a separate set of audio files for each reel, usually one file for each playback channel (left, centre, right, LFE, left surround, right surround). Before starting the DCP authoring process itself, the image files have to be scaled to the DCP resolution container of either 2048 x 1080 or 4096 x 2160. Necessary colour space transformations are normally applied during DCP creation via LUTs or matrix transforms.

In the next step, the images and audio files are imported into the DCP creator software reel by reel. At this point settings for colour space transformation and several other parameters can be made. Now the reels are arranged in one or more Composition Playlists (CPL). Finally, by pressing a button the DCP creation process is started. The software compresses the images to JPEG 2000, wraps audio and images in MXF files and places them together with some XML files in a folder on the hard disk. All files in this folder comprise the DCP that can be directly copied to a DCP playback server and shown in a cinema.

If the goal is to create an encrypted DCP some additional steps are necessary. For each reel encryption is switched on. The encryption takes place during DCP creation after JPEG 2000 encoding. In addition to the DCP the software creates another so-called digest file that contains the encryption keys that are necessary to create the KDMs necessary for playback. This file has to be stored in a safe and secure place because without it there is no chance of decrypting the DCP. To create a KDM two things are needed: the digest file from the DCP creator software and the certificate of the playback server on which the DCP shall be played. Both files are imported into the KDM generator software. Now, the operator selects the time window for playback and presses a button to create the KDM. The result is a small file on the hard disk that can be send via email or on a USB memory stick to the cinema.

[26] see SMPTE ST 428-1:2006

All in all, the complete process is no more complicated than authoring a video DVD.

# 5 Archiving Digital Cinema

## 5.1 General considerations

The transition from film to digital cinema is going to have a very large impact on archives and there are positive as well as negative aspects connected to this process. On the one hand archives will have to cope with material that is going to be delivered in a wide range of digital formats, of which a Digital Cinema Package can be one. On the other hand digital technologies including the DCP provide efficient ways to publish and distribute archived material on different, and possibly very high, quality levels. Unfortunately, archiving of digital data follows very different principles compared to what film archives are used to. While quality degradation of the content over time can be reduced to zero as long as data is only copied but not converted during migration to new media, the loss in case of any errors at critical points in the complete system can be total.

The fundamental difference in archiving digital data compared to traditional films, books or similar materials can be found in the longevity of the storage media and the characteristics of degradation over time. Digital storage media often have a theoretical archival life of 15 to 30 years[27] according to the statements of the vendors. This is much less than what can be expected from traditional media like film. In practice this lifetime is reduced even more because of the strong risk of obsolescence of drives, software and systems. A magnetic data tape in its best possible condition is worthless if the tape drive, the storage software and the computer systems that work with the drive and software are no longer available. Film can always be viewed, projected or scanned. Essentially, this means that in the digital world frequent migration processes are mandatory. If this migration is omitted because of lack of money or other resources or because of other external circumstances, there is a very strong risk of losing the collection. If a magnetic tape is discovered after 50 years in the attic it may be useless while film under the same circumstances may very well have lasted and can be of use.

Another important point for archives to consider is which digital formats to accept for deposit, especially where legal deposit rules are in force. DCPs are the digital equivalent to film prints that are delivered to the cinemas and the archives that accept film prints for deposit. The DCP may have a comparable quality level but most, if not all, DCPs of commercial productions will be encrypted. And while the quality level is already very high it probably does not match that of an interpositive because of the use of lossy compression. On the positive side, the amount of data encountered from a DCP can be handled in today's IT infrastructure without problems while uncompressed or lossless compressed digital masters are still difficult to handle.

## 5.2 Encryption

While the image quality of a DCP that is deposited at an archive may be beyond that of a film print, encryption poses the most significant problem. As an archive element the DCP is only useful for the archive if it also holds the AES keys that were used to encrypt the

[27] see http://cache-a.com/products.php

image and sound track files. An encrypted DCP without keys is of no use at all because it can not even be played back. Also a DCP with a KDM for a specific playback server and projection system is only of very limited use for the archive. With a normal KDM the DCP can only be played back on the systems that are explicitly included in the KDM. This DCP can neither be converted to other formats for preview of long-term preservation nor can it be played back on other systems if the system the KDM was produced for is no longer serviceable. Also the time limit of the KDM may become a problem because the DCP can not be played back any more after the end date and time stated in the KDM.

Because of the high image and sound quality of a DCP and because of the fact that digital data is relatively easy to copy without any loss in quality compared to film, content owners are very reluctant to give unencrypted DCPs to archives. There are two important aspects to this practice. On the one hand content owners may fear that archives are not able to provide appropriate protection to the material on their premises. This problem can be solved by setting up suitable security measures that prevent unauthorized access of the material. On the other hand there is the risk of content theft during transport or transmission of DCPs to an archive. This can only be prevented by encryption. One possible solution could be to provide encrypted DCPs to archives and also delivery KDMs that can be used with special software to decrypt the DCPs in a secure and controlled environment on the archive's premises. This would secure the transmission but also give archives the possibility to take care of the long-term preservation of today's digital films for the future. The process is straightforward and as easy as playing back a DCP as described in the next section.

## 5.3 Playback of DCPs and other archival formats

Normally, D-Cinema playback servers and D-Cinema projectors are used to screen DCPs. These systems incorporate the security measures of the DCI Specification. Unfortunately, they are also expensive systems and oversized for many applications. Most especially the decoding of the JPEG 2000 compressed images in the DCP is a very demanding task that could in the past only be carried out in real- time by hardware decoding boards that use specialized integrated circuits. With the advent of more powerful personal computers and technologies like graphics accelerator boards that can also be used for other computationally complex tasks this has changed significantly. Today, it is possible to play back a 2K DCP on a PC equipped with a suitable graphics accelerator in real-time. And if it is not required to play the DCP in full resolution, a lower resolution preview can also be accomplished on a decent standard office PC.

Fraunhofer's easyDCP Player[28] is one software package can be used to play back DCPs for preview and quality control purposes on standard PC equipment. This program can also be very useful for archives because it allows viewing DCPs also in other frame rates than 24 for 48 FPS and in addition it is possible to extract images from DCP to JPEG 2000 or TIFF file sequences. Provided that a KDM is supplied for the software also encrypted DCPs can be viewed and converted into unencrypted JPEG 2000 or TIFF files. The technical possibilities are there to accomplish this. However, the important question is to convince content owners that they provide KDMs for this solution and that the software is operated in a secure environment where unauthorized access can definitely be avoided.

[28] see http://www.iis.fraunhofer.de/en/bf/bsy/produkte/easydcp/easydcpplayer/index.jsp

In most cases the DCP is delivered to a cinema on a portable USB hard disk. To play back the DCP the hard disk is connected to the DCP playback server. Then the ingest function is selected. The server accesses the hard disk and looks for DCPs on it. Now, the operator can select which DCPs he wants to ingest. The server then copies the DCPs to its internal hard disks. Depending on the size of the DCPs this might take some time (in some cases this can be more than one hour). During ingest the DCPs are checked for errors using the hash values that were calculated when the DCP was created. If the DCP is encrypted, the appropriate KDM for the playback server in question must be available. KDMs are normally delivered on USB memory sticks or via email. The KDMs are ingested to the DCP playback server in a similar way. The USB stick is connected to the server, scanned for KDMs that then can be selected and copied to the server's hard disks. Since the size of KDM is very small this usually takes only a few seconds. The operator can also view the KDM information and check the time window during that playback of the film is allowed by each KDM. Ultimately, the operator prepares a play list with all DCPs for a certain screening and then just has to press the play button to start the show.

# 6 Conclusion

Many digital technologies can be used to the advantage of film archives. They can simplify distribution and make sophisticated restoration processes for degraded film material possible. With the Digital Cinema Package there is also an efficient way to distribute archive films in a very high quality to digital cinemas. However, there are also negative sides. While it always has been possible to acquire release prints and store them for future generations, even without the consent of the content owner, this is now significantly more difficult if not impossible with encrypted DCPs. Archives not only have to take care of the specific properties of digital data and develop ways to store the data for a very long time frame. They also have to work out, in co-operation with the content producers and rights owners, how to preserve digital films and simultaneously satisfy the rights holders' needs for content security. This article describes only a very small part of the world of digital technologies for cinema. Traditional archives need to participate in these technological advances to be able to carry out their mission in the future.

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