Automated industrial Digitization of Betacam tapes

— with MXF generation and validation

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Digitization has became a mandatory step that media stakeholders have to face up to, in order to cope with the increasingly digital nature of production, archiving and distribution workflows. The Italian public-service broadcaster, RAI, is heavily involved in this step and is trying to automate its digitization operations as much as possible ... whilst guaranteeing the quality of the generated files.

This article describes what RAI has done about digitization in the specific case of Betacam-like tapes. It also describes the devices and software employed, giving particular emphasis to quality issues.

1. Introduction

The digitization of archive material is an inescapable issue that broadcasters have to face sooner or later. Analogue media carriers are inevitably becoming obsolescent over time, due to the decreasing availability of compatible equipment, while the newer digital domain guarantees many advantages such as:

- better control over the quality of the essence in postproduction;
- the ability to perform computer-assisted enhancements;
- the ability to use all the general features found in IT environments.

However, digitization has a complex workflow where several hardware devices and software components of different kinds are required, and qualified personnel have to be involved. Things can become critical if the media carriers (e.g. a videocassette or a film) are in poor condition; for example, when they have been badly preserved or simply when they are very old.

Betacam is a family of audiovisual cassettes for professional use, produced by Sony since the beginning of the 1980s. Several different versions of the Betacam format have been released over the years: Betacam SP, Betacam SX, Betacam Digital and Betacam IMX. The format is still widely in use, especially in the last revision called Betacam IMX.

There are two physical formats of Betacam: ***small*** (15.1 x 9.5 cm) and ***large*** (25.3 x 14.4 cm). The tape is ½-inch wide and the maximum duration of the contained archive material spans from a few minutes to a couple of hours. The tape has space for one video track, up to 8 audio tracks depending on the format, and a track for linear timecode.

Betacam SP records the audiovisual material as analogue signals. As RAI's archives hold a significant amount of Betacam SP tapes, the RAI Archives Department decided to digitize them first because, even if not totally obsolete, this format is certainly outdated.

The digitization chain put in place by RAI for this purpose is described in this article.

2. The digitization flow

The overall process of digitization as envisaged by RAI is shown in *Fig. 1*.

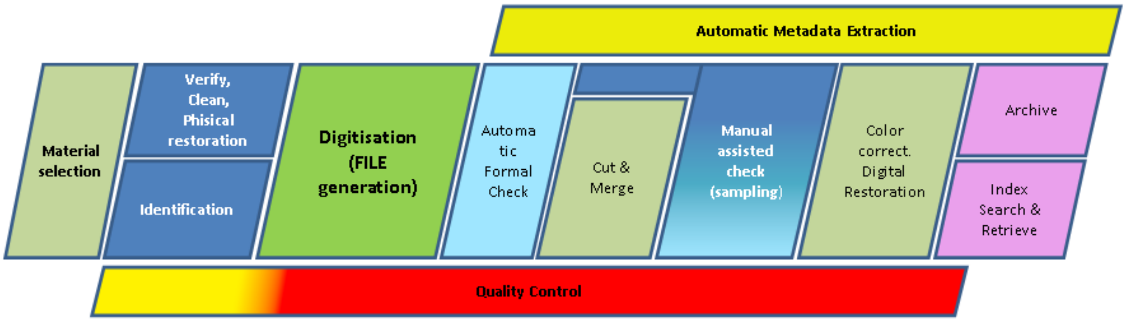

Figure 1
A complete digitization workflow. *Automatic Metadata Extraction and Quality Control are traversal activities but, in this article, Quality Control after the digitization (the red bar) is of particular interest.*

2.1. Material selection

Starting from the left of *Fig. 1*, the first phase is the selection of the material to digitize. This operation is totally manual and depends on business considerations (e.g. digitize what is important for production) and urgency criteria. A careful analysis of the risk of loss is done in order to decide what to digitize first and minimize those risks. It is not unusual to select material depending on the specific carrier and/or the category of the content (e.g. all the cassettes containing the shooting of an event, or all Betacam SP cassettes of a certain collection).

2.2. Identification

Each carrier should be well identified, checking that the content is what was expected. In fact, practical experience shows that the content (especially for older cassettes) is not even known *a priori* when doing this kind of cross-check. During this phase it is advisable to stick a label on the carriers – if not yet present – such as a barcode or QRcode [1], thus enabling automatic detection (e.g. with infrared barcode readers).

2.3. Verify, clean and physically restore

Carriers should be assessed for quality at this stage, to decide if they require some special treatment before the automatic workflow. If, for example, some tapes are found to be affected by *Sticky-shed syndrome* [2], they should be treated with a heating phase in specific ovens. These particular physical and chemical restorations are usually expensive, and to what extent to apply them is a choice that depends primarily on the intrinsic value of the content.

1. There exist many different kinds of barcode (linear code) and QRcode (two dimensional code), each of which is described by a specific standard. *Section 3.1* outlines those that are used in the RAI system.

2.4. Digitization

This is the core phase of the entire flow. From the playout of the original carrier, one or more files are generated. If the goal of digitization – like in RAI's case – is to produce master files (i.e. files that can replace the original material), it is necessary to carefully decide the format of the output (codec, bitrate etc.) in order to maximize quality whilst limiting the storage occupancy. Other important issues to consider when choosing such formats are the foreseen interoperability of the format, and how current is the adopted standard.

2.5. Automatic file format check

After digitization, it is advisable to perform a formal check on the compliance of the generated files with respect to the standards. Here the problem could be that standards are often complex, sometimes ambiguous, and there exist different flavours and implementations. This is the case, for example, with MXF [1] for which the RAI adopted flavour D-10 as explained in *Section 3.2*.

Readers who want to be introduced to MXF are referred to [2][3].

2.6. Cut and Merge

Cut is an activity where cutting of the material can be done by editorial staff, aimed at obtaining a single file for each editorial object (e.g., a programme or a news story). Conversely, merge can be used for sticking together parts that became disjointed during the digitization phase (e.g., long content spanning more than one cassette). These cut and merge operations can be logical (e.g. in the form of an EDL), after which programmes are well consolidated and it is possible to get a full media representation of them.

In our system at RAI, a rough cut is done using a dedicated web interface that makes use of keyframes [3] and a proxy of the material. Once the cut operation is completed, the resulting multimedia files are consolidated and prepared for preservation. This preparation includes calculation of checksums, both on entire files and on each video frame. Checksums are important for fixity checking; having them for each frame allows us to discover where potential corruptions are located and to validate excerpts of the material.

2.7. Manually-assisted check

This is the phase where most of the quality control is performed. Quality control is very much a subjective procedure, as automated algorithms are currently not capable of giving quality estimates with an acceptable accuracy or, at least, are not viable in every application. Thus, for the detection of audiovisual defects, it is usually necessary to employ specialized personnel and dedicated interfaces/software. Nevertheless, automatic metadata extraction and intelligent software play an important role in this activity because they can furnish useful information that allows us to reduce the time and costs of the operation.

2. Sticky-shed syndrome is a condition created by the deterioration of the binders in a magnetic tape, which hold the iron oxide (magnetisable) coating to its plastic carrier. This deterioration sometimes renders the tape unusable.

3. Keyframes are still images (extracted from the video) that represent a seamless piece of video with almost visually homogeneous content. Typical duration of these pieces (shots) is between a few seconds and a few tens of seconds.

Abbreviations

BDS	(RAI) Betacam Digitization System	**MXF**	Material eXchange Format
EDL	Edit Decision List	**PCM**	Pulse Code Modulation
FTP	File Transfer Protocol	**QC**	Quality Control
KLV	(SMPTE) Key Length Value	**SMPTE**	Society of Motion Picture and Television Engineers (USA) http://www.smpte.org/
LAN	Local Area Network		
LTO	Linear Tape Open	**VTR**	Video Tape Recorder

2.8. Digital restoration

Once the files has been assessed for quality issues, they can be further improved in quality by means of digital techniques such as colour correction, and generic defect correction e.g. for old and poor-quality material. This is a specialized activity (undergoing further research) that will not be investigated here.

2.9. Archival

Files are usually archived for later usage. This is an important phase, especially if the files are considered as master quality and will replace the old carriers. In this case it is particularly necessary to assure the integrity of the files over time. One strategy could be to make multiple copies and to use storage of good quality and/or of different base technologies (e.g., LTO tapes and disks).

Reliable storage and preservation are non-trivial tasks because of the high bitrates used (MXF/D-10 files run at approximately 60 Mbit/s, resulting in about 30 GBytes per hour) and the non-negligible error rates of base technology devices.

2.10. Indexing, Search and Retrieval

Last but not less important, material has to be indexed for effective search and retrieval. The minimal required access is by identification (title or identification code) while indexing with a wider range of metadata (even automatic like transcribed text) is recommended.

2.11. Role of quality control

As could be seen in *Fig. 1*, quality control (QC) is crucial and spans across the whole workflow. In principle it should be applied whenever the material is in danger of losing its quality. In this work we concentrate on QC in the digital domain i.e. after file generation. It has been said that this kind of control is time consuming and expensive ... hence the importance of automatic content analysis with extraction of metadata that are useful for improving the process.

Figure 2
Indelt Robotic (Broadcart T3)

3. Tools for automating the digitization

3.1. Robotic and Cleaner

The RAI Betacam Digitization System (BDS) uses a small robotic (Broadcart T3, see *Fig. 2*), manufactured and sold by an Italian company called Indelt [4].

4. http://www.indelt.it

It can hold up to 60 Betacam tapes (both large and small) in a parallelepiped-shaped rotating library. Each side of the library has to be configured for hosting large or small tapes and has 15 places. The automated robotic arm has a vertical degree of movement and disposes of two grippers (the second just as a backup); near the gripper there is an infrared barcode reader (working with *interleaved 2 of 5* flavour) necessary to identify the tapes.

Figure 3
Indelt Betacam Cleaner

Up to four VTRs can find place in the bottom part of the robotic or, as for our system, 3 VTRs and an Indelt Betacam Cleaner. The movements can be controlled via a serial connection (RS232) and a set of high level commands (e.g. "move tape laying at location J2 to VTR1") has been implemented.

The Cleaner (*Fig. 3)* is a device also designed by Indelt. It works with a dry cleaning tape that rubs against the magnetic tape in order to eliminate dust and oxide waste. It can be controlled via a serial RS232 connection and returns a report including the signalling of tape overtensions, transparency and abnormal reflections. Its operating speed is approximately ten times faster than normal play speed so that it can serve (as total throughput) three simultaneous VTR playouts.

This kind of robotic automation allows us to work through large volumes in a short period of time: a configuration with 3 VTRs and a Cleaner can deal with more than 50 hours of material in a day. This implies that, with an average tape duration of one hour, it is possible to digitize all the tapes loaded in the robotic in 24 hours, hence allowing the optimization of the unload/load operation, which is organized on a daily basis.

So far, RAI has worked through more than 1200 hours of material coming from different collections of interest, the outcomes being temporarily stored on around 60 LTO4 tapes.

3.2. Playout and digitization devices

The BSD produces MXF audiovisual files as its output. RAI chose to adopt a professional Sony VTR i.e. model MSW-2000 *(Fig. 4)* to play and digitize the content. A hardware extension called e-VTR *(Fig. 5)* is available for this model that allows it to connect directly to a LAN and access the audiovisual content simply via FTP [5] protocol. Through the FTP interface, it is possible to get a file containing the whole material stored on the tape.

Figure 4
Sony MSW-2000

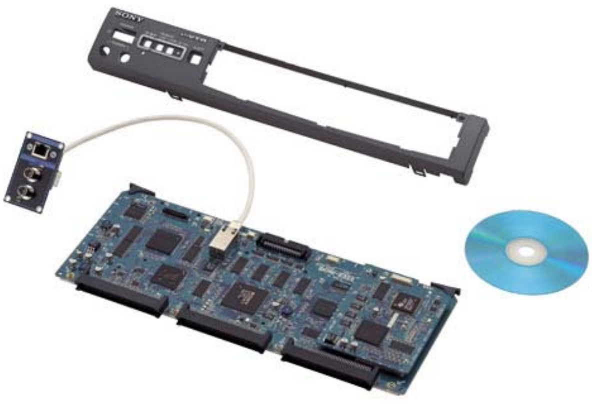

Figure 5
Sony e-VTR BKMW-E3000

Among the detected criticalities, there are some minor problems such as the fact that this process gets interrupted in cases where a certain portion of the tape is not recorded (e.g. tape containing rough material with non-based parts between a rush and the other). RAI worked around this prob-

5. File Transfer Protocol, is a well known TCP/IP protocol that allows us to reliably get files after an authenticated login to the source system

lem by continuing the acquisition from the current position again and again until the end of the tape had been reached. In this case the digitization process results in several files.

The resulting MXF files are compliant to standard SMPTE 386M [4]. The bitrate is 50 Mbit/s for the video and an additional 13 Mbit/s for the eight audio tracks (uncompressed PCM 16-bit, 48 KHz), for a total of around 63 Mbit/s KLV overhead included. In this type of file, the essence is coded intra only, meaning that no temporal redundancy is exploited for compression, and each frame can be independently and randomly accessed. Video, audio and metadata pertaining to a single frame form what is called an *edit unit* (see *Fig. 6*)

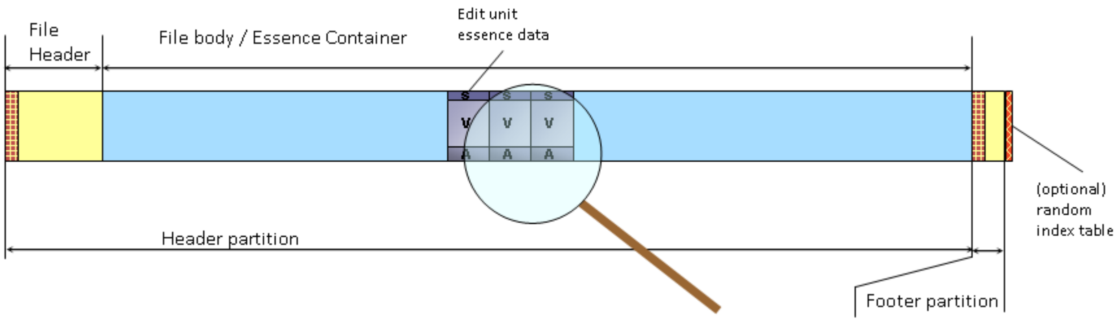

Figure 6
Structure of an MXF/D-10 file

4. Quality control

It has already been mentioned that quality control is very important to assure that the quality level of the audiovisual content is not below the original level. Within the digitization workflow, the most delicate phase is the transition from an analogue signal generated from the reading of a removable carrier, to a digital file to be used in IT systems.

In early 2000, RAI conducted a set of exhaustive tests [5] within the EBU group P/DTR, which showed that the bitrate and coding scheme obtainable with the Sony eVTR (namely MXF/D-10 50 Mbit/s) is sufficient to preserve the quality of the content stored on legacy Betacam SP tapes. This means that no sensitive artefacts are introduced, even after several copy generations. In order to ensure that the reading operation happens in optimal conditions, RAI performs a prior cleaning process. An additional electronic board has also been designed and implemented to monitor the digitization phase and detect potential problems with the tape and player.

4.1. A specific hardware for measuring the quality of digitization

The process of reading a magnetic tape by means of a magnetic head is critical and can be affected by several problems such as head wear and misalignment, the presence of dust or oxide waste both on the tape and on the heads, etc. We designed a specific hardware in order to collect some useful parameters that can be used fruitfully for detecting these types of problems.

The board, shown in *Figs 7 & 8*, is based on a microcontroller. It fetches some of the internal signals from the internal VTR boards, the linear timecode signal from the external XLR connector and the output signals from the DB50 serial VTR. The output of the QC board can be collected via a serial RS232 connection and consists of a sequence of parameters given for each video field, namely the radiofrequency envelope of the luminance and chrominance, the luminance and chrominance dropout [6] position and duration, along with start-stop and positioning commands received by the VTR.

6. This is a typical video television defect with a small video loss. Because of the *raster* nature of TV video, the defect is a horizontal section of lines that usually appear black or white. The reason is bad reading, either due to a bad tape, faulty heads or a combination of the two.

Figure 7
RAI QC board

Figure 8
RAI QC board mounted inside MSW-2000

With further elaboration we found this kind of parameter very useful in order to detect native problems on the tape and VTR heads. *Section 4.3* explains how these parameters are used within the interface for annotation of the technical defects.

4.2. Tools for formally checking the files

Formal checking of files is not a trivial task because of the complexity of standards and their numerous variants. RAI developed two specific tools for dealing with MXF files and specifically targeted to the D-10 variant. The first tool is called *d10ffdewrap*. It is able to perform the following checks on the overall file: (i) header and footer binary dumps (for later analysis); (ii) header and footer md5 checksums; (iii) overall md5 checksum; and (iv) extraction of components (m2v for video, wav for audio, timecode as text).

Moreover, for each frame, it is able to: (i) extract the timecode; (ii) calculate the edit unit checksum; (iii) calculate video and audio checksums within the edit unit; (iv) calculate for each channel the loudness (RMS) [7] [6]; and (v) find and fix corrupted video frames. This last feature is made possible using a specific library which performs an MPEG-2 decoding on each single edit unit and reports errors if the picture is not compliant with the standard. In this case it is possible to replace the corrupted edit unit with a concealment one.

The other tool, called *MXFTechMetadataExtractor*, focuses on the header and works with different flavours of MXF including D-10. It is able to check the consistency of the header and to extract some metadata, as specified in *Table 1* on the next page.

Formal checking is of great importance for interoperability as better explained in *Section 5*.

4.3. An interface for manual-assisted assessing of material

Even if a formal check is important and can often be done automatically, a really important aspect is undoubtedly the investigation of the real quality of the audio and video components (also known as baseband). This operation has a strong subjective component and, even with the latest innovative computer science algorithms, it cannot be fully automated. Nevertheless, automatic metadata extraction can give very useful contributions as explained later on.

7. Measurement is performed at non-conventional intervals of 40 ms (i.e. on each video-frame). “K” frequency weighting and mean-square calculation are performed as specified in ITU-R BS.1770-2 [6]

Table 1 – MXFTechMetadataExtractor, MXF extracted Header metadata

Key	Value example	Key	Value example
OperationalPattern	OP1a	VideoActiveLinesPerFrame	576
Material UUID (UMID)	0x060a2b340101010501010d00130000009998c1c26d944d509882e092d9218f6b	DisplayWidth	720
Duration	1500 [s]	AudioChannelCount	8
EssenceContainer	D10	SoundEssenceCoding	uncompressed
EditRate	25:1	AudioSamplingRate	48000:1
AspectRatio	4:3	AudioQuantizationBits	16 [bits]
ComponentDepth	8 [bits]		

RAI developed a Web application for the assisted annotation of audiovisual defects. In a single screen *(Fig. 9)* it is possible to watch and hear the media with the possibility of seeking to any point on the timeline. The user can annotate defects on the basis of time intervals, defect types and severity. Finally, in the bottom part, there is an area where several charts of quality-related parameters can be displayed; this is for aiding the operator who can scan along the timeline and find potentially affected segments from the identification of unusual patterns in the curves of the video or audio tracks.

As can be seen in *Fig. 9*, we can plot the parameters of the luminance and chrominance made by our additional hardware (as described in *Section 3.1*) and various video analysis features such as luminance, contrast, hue and directionality. While the first gives us information on the “quality” of the

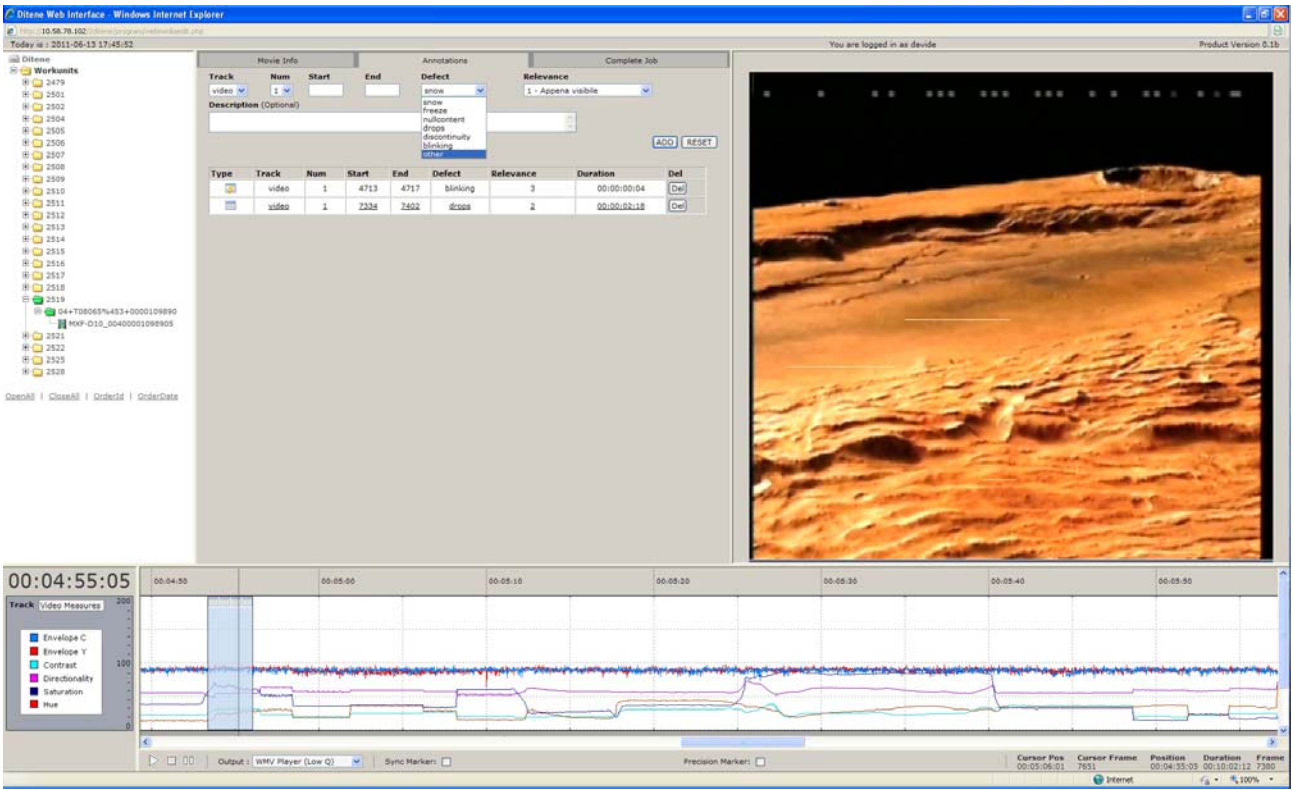

Figure 9
RAI Web interface for technical annotation of audio-video defects

digitization itself in terms of tape, heads and reading, the second works on the pure content once read. In fact there might be cases in which the analysis of digitization signals is not sufficient to detect failures in the content, especially when these are inherited from previous format migrations.

It is planned in future to add other charts such as loudness in each audio channel, along with the keyframes extracted with a shot detection tool and other kinds of parameters that could be useful in aiding the annotation of defects. To avoid the danger of information overload, a substantive research effort is needed to identify which low-level features are better suited to represent quality-related information. The objective is to have a meaningful summary indicating, for example, a set of attention points where it is highly probable that a defect will be encountered.

The time saved in defect annotation, by using automatically-extracted quality metadata, has not been evaluated precisely but is evidently notable while keeping the accuracy high.

5. Interoperability

Experience shows that, even when using devices from the same vendor, there could be blocking problems. The best approach would be that each component (whether software or hardware) uses standard definitions rigorously; in particular, there should be strict and rigorous validators to run when delivering and receiving new material. Unfortunately, standards are often large and complex (e.g. MXF) and are open to different interpretations when vendors offer different implementations. More than this, some players (both software and hardware) are tolerant in different ways to minor problems and this can cause inconsistencies. For sure, checking a file along with every single adopted software and device is not a winning approach but often remains a practical solution.

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Within this project, RAI found some minor interoperability problems that have been addressed by fixing some corrupted MPEG-2 frames and filling in correctly some MXF header parameters such as the duration. In fact, even if the MXF standard allows us to leave the field duration undefined, most software players in that case may infer a wrong value and show some malfunctions (e.g. seeking).

6. Conclusions

RAI is gaining valuable experience in the mandatory task of carrying out high-quality digitization of archive material stored on tapes. The production of master files implies big issues relating to automation and quality control during this delicate phase. The file format and profile choice are important in order to guarantee a good compromise between quality and storage occupation, interoperability and future-proof support.

A certain number of steps in the workflow still remain manual but automatic content-analysis tools allow us to extract meaningful metadata that can help in difficult tasks such as quality control and effective access. Future works will concentrate firstly on optimization of the digitization workflow, with due respect to quality control, and later on how to organize and store the large amount of heavy master files in such a way that access to them is fast and efficient.

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