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Knowledge database and report on tape condition

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ABSTRACT	There are approximately 1 million U-Matic tapes on archive shelves across Europe, the majority of which are over 20 years old. Between 20% and 80% are likely to be difficult and expensive to transfer. Despite the magnitude of this problem, comparatively little information is currently available to archives on exactly what problems to expect when planning or executing U-Matic tape transfer projects. This report provides a set of guidelines for U-Matic tape transfer accompanied by quantitative tables that reveal what tape playability problems to expect.
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1. Document Scope

This report presents an analysis of the tape playability problems encountered during the transfer of 50,000 U-Matic tapes from the archives of the Institut National de l'Audiovisuel (INA) in France.

2. Executive Summary

There are approximately 1 million U-Matic tapes on archive shelves across Europe, the majority of which are over 20 years old. Between 20% and 80% are likely to be difficult and expensive to transfer.

Despite the magnitude of this problem, comparatively little information is currently available to archives on exactly what problems to expect when planning or executing U-Matic tape transfer projects.

This report provides a set of guidelines for U-Matic tape transfer accompanied by quantitative tables that reveal what tape playability problems to expect.

3. Overview of this report

This report is intended to be used by people who want to:

- Assess the condition and risk of loss of their U-Matic tape collections
- Plan and cost U-Matic tape transfer projects
- Execute U-Matic tape transfer projects in an efficient and cost effective way

This report contains the following sections:

Section 4 provides an overview of U-Matic tape in terms of years of production, manufacturers, holdings of audiovisual archives, the extent to which U-Matic is problematic to transfer, and the cost and time need to transfer U-Matic tapes into digital form.

Section 5 contains guidelines and recommendations for planning and executing U-Matic tape transfer projects, including how to use the Tape Playability Tables in this report when costing or executing tape transfer projects.

Section 6 contains a series of Tape Playability Tables that make it easy to identify whether playability problems are likely for a particular U-Matic tape by using a red/yellow/green ‘traffic light’ system to highlight the problems with different brands, years and tape formulations.

Section 7 summarises the major findings of this report.

The report also includes a set of appendices containing further information, for example more details on the problems that can occur when transferring U-Matic tapes including the different types of defect (head clogging, dropouts, sticky tapes, etc.), which defects are common and which are rare, which are playability problems due to the formulation/degradation of the media, and what types of treatment are required.

4. Introduction to U-Matic

The U-Matic tape format was introduced by Sony in 1971 and rapidly became widely adopted by the broadcast industry due to the benefits of using a cassette over previously used open reel formats. The tape is 3/4 inches wide and named after the shape of the tape path when it was threaded around the helical video head drum, which resembles the letter U. Standard U-Matic has a resolution of 250 lines.

In the early 1980s, Sony introduced the high-band or BVU (Broadcast Video U-Matic) format with improved colour and lowered noise. The 'original' U-Matic format is now known as 'Low-band'. High-band U-Matic was popular in news and location programme-making, frequently replacing film in everyday production.

By the early 1990s, Sony's 1/2" Betacam SP format had all but replaced BVU in the broadcast industry, although U-Matic remained in use in corporate and 'budget' programme making. The window of mainstream use of U-Matic is therefore between the mid-70s and early 90s with peak use in the mid 80s. Although U-Matic is no longer used in professional broadcasting following replacement by betacam in the early 1990s, it still remains in use today in some budget applications. Full details can be found in Appendix A: Archive holdings of U-Matic.

We estimate that the total number of U-Matic tapes in Europe is still well over one million, most of which are between 20 and 40 years old.

As with most tape based AV media, there are a range of problems that may be encountered when playing back U-Matic tapes. These problems are described in detail in Appendix D: Problems encountered during U-Matic tape transfer and include:

- Obsolete and hard to obtain playback equipment
- Lack of necessary skills or need for specialised equipment, e.g. cleaners
- Decay of the media, e.g. due to chemical decomposition
- Dirt, dust, mould or other forms of tape contamination that can come from everyday use, poor storage conditions, or disasters such as fire or flooding.
- Wear and tear or other forms of damage to the tape or the cassette due to use or mishandling both in the production and archive environments.
- Poor quality signal due to the way the original recording was made, e.g. due to head misalignment, worn pinch rollers, dirt on the tape or heads.
- Difficulty in identifying the content, e.g. due to lack of cataloguing

Of these, technical obsolescence and media decay are the biggest problems. U-Matic tape decks are obsolete and no longer supported. This immediately presents archives with difficulties when sourcing and maintaining suitable playback equipment as well as finding or training operators with the necessary skills. U-Matic tapes themselves also suffer from a range of problems and, as shown by the results of the IASA2003 [1] survey of AV archives from across the world, more U-Matic tapes are in a state of decay or giving cause for concern than any other video format. This includes earlier open reel formats such as 2 inch and 1 inch tape.

Somewhere between 20% and 80% of all U-Matic tapes are showing obvious signs of decay or are giving the archives holding them cause for concern[2].

As a result many of Europe's large audiovisual archives are already in the process of migrating their U-Matic tapes, or they have already completed this work. Full details can be found in Appendix B: U-Matic problems found by archives.

U-Matic is widely considered by the major broadcast archives in Europe as the top priority format for video preservation.

The BBC estimates that it costs 5 times as much to transfer difficult media (if it can be transferred at all) than it does to transfer media that plays back first time[3]. As a result, the problematic proportion of media in AV archives can represent the bulk of the cost of transfer.

U-Matic transfer costs between 50 – 100 Euros per hour of programme material when tapes are in good condition, rising to as much as 500 Euros per hour for problematic tapes.

The cost of transfer includes inspection, preparation, digitisation, checking and quality control, and the purchase of new media stock. Full details can be found in Appendix C: Cost of transfer for U-Matic. The cost of transfer is largely dependent

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[1] Survey of Endangered Audiovisual Carriers: http://portal.unesco.org/ci/en/ev.php-URL_ID=13437&URL_DO=DO_TOPIC&URL_SECTION=201.html

[2] Estimates vary from the self assessment of TAPE archives that believe that 70% of archive content is in good condition to the reverse analysis of the TAPE results by PrestoSpace that estimates 80% of the material may have problems. The TAPE survey also revealed that only 15% of respondents have a combination of climate control, trained staff and a preservation programme, so the TAPE self-assessment is likely to be an underestimate of the real extent of problems with U-Matic. Results for specific archives include INA where approx 20% of U-Matic tapes have one or more playability problems and the BBC where 40% of their U-Matic tapes failed to playback first time indicating some form of problem.

[3] Most of this increase in cost is due to the increase in operator time required rather than the need for expensive equipment. The BBC estimate that for U-Matic in good condition it takes 1.5 hours of operator time per hour of content to transfer U-Matic followed by 1.3 hours per hour for checking and quality control. For U-Matics in poor condition, this rises to 5 hours per hour for transfer followed by 2 hours per hour for checking. INA process difficult U-Matic tapes using a specialised 'clinical treatment' chain. Tapes will typically need to be repeated played using many trials of machine adjustments. This treatment can take one full day of specific work for each tape to be successfully played back chunk by chunk.

on the amount of labour involved, which limits the volumes that can be transferred even using a factory approach[4].

U-Matic transfers take between 1-2 hours of operator time per hour of programme material for tapes in good condition, rising to 5-10 hours per hour or more for difficult media.

Whilst there are clearly huge numbers of U-Matic tapes on shelves and much of these are at risk and will be expensive to transfer, relatively little quantitative information is available on the specific problems that exist. This lack of specific and quantified information is a major problem when planning and executing transfer projects, especially considering the costs involved in attempting to transfer tapes that have playability problems. This report aims to provide some of this information.

[4] Using a production line approach running 24x7, ORF achieve up to 7000 hrs of content transfer per operator per year for good media, but this drops to 800 hrs per year for difficult media where skilled operators are needed and the process is more labour intensive. For large archives where U-Matic collections can be 50,000 tapes or more, this shows that parallel chains with teams of operators will be required and even then transfer of the whole collection can take several years.

5. Guidelines and Recommendations

This section provides some simple guidelines for planning or executing U-Matic tape transfer projects.

The guidelines, recommendations and playability tables in this report are also of use for those who want to assess the condition of their U-Matic collections and the potential risk of loss if preservation or digitisation action is not taken.

The guidelines build upon recommendations from other parts of the PrestoSpace project, including how to approach the problem of difficult media[5] and the guidelines, cost models and calculators for digitisation and storage projects[6]. We suggest reading these other sources of information first.

For U-Matic tape transfer projects, our specific additional recommendations are to:

1. Create a Technical Map of your collection before you attempt a U-Matic transfer project. This will provide an invaluable starting point when deciding on the best way to proceed. The map should include:
    a. How many U-Matic tapes you have
    b. Who manufactured them
    c. How old they are

2. Use the Technical Map along with the Tape Playability Tables in this report to determine the extent to which you are likely to have playability problems when transferring your U-Matic tapes.

    a. If more than 10% of your U-Matic tapes are likely to be problematic, or you can isolate a group of tapes that are likely to be worse than others, then consider using a *triage*[7] stage in your transfer workflow. This will make the process a lot more efficient and will save costs.

    b. If more than 25% of your U-Matic tapes are likely to be problematic, then be aware that this group of tapes will probably at least double the total cost of transferring the whole collection. Consider whether you need to prioritise how your transfer budget is spent.

3. It is often effective to use a triage step when executing a transfer project. During the triage step, look at the serial number on each individual tape and

[5] See PrestoSpace D5.3 Difficult Media available from http://www.prestospace.org

[6] See the PrestoSpace website on Storage and Management: http://prestospace-sam.ssl.co.uk/

[7] Triage is a step in the transfer workflow when each media item is examined and based on the observed condition, or estimation of problems that could occur during transfer, then the item is assigned to a particular in-house transfer chain or operator, or to a particular service provider who is best suited to deal with the specific problems that are likely to be encountered. More details can be found in PrestoSpace D5.3 'Difficult Media'.

use the Serial Number Converter and Tape Playability Tables to determine what problems are likely to occur during transfer for that particular tape.

4. Some tape formulations can cause more wear and tear on tape heads than others. If you are transferring a collection of tapes that are made by more than one manufacturer then consider the order in which transfer takes place,

    a. Consider starting first with softer formulations (e.g. AGFA, AMPEX) and then move on to tapes with harder formulations (e.g. FUJI) towards the end of the transfer project.

    b. Brands that have high levels of head clogging and sticky shed as shown in the playability tables tend to be the ones with softer formulations and hence will cause less head wear.

5. As the transfer project progresses, carefully monitor the actual problems encountered and use this information to refine the approach used. The tables in this report are based on the experience of one particular organisation: factors such as your particular archive storage environment may cause you to experience different results.

6. Playability problems are only some of the challenges you are likely to face[8]. Therefore, it is important to consider the playability problems described in this report in the context of all the other problems that may occur and to use a transfer workflow that allows all the problems to be dealt with efficiently.

The playability tables in this report have been derived from the specific experience of INA with their tapes and are not necessarily representative of all U-Matic archives.

When planning and executing a large transfer project, we also recommend developing a set of playability tables that are customised to the U-Matic collection being transferred. This can be done as part of the process outlined above, e.g. by collecting information when transfers take place.

If the tables in this report do not give good coverage of the tape brands or years in your archive, or there are reasons to believe your circumstances are different, then a set of more appropriate set of playability tables should be built before starting the bulk of the transfers. This is the best way to get an accurate picture of what will happen for your particular U-Matic collection.

A detailed description of the analysis method used in this report is provided in Appendix F: Analysis Method. The general steps involved in creating playability tables are summarised below:

[8] Other issues to contend with might include dirt or mould due to the environment in which the tapes have been stored or used, damage to the tapes due to usage or neglect, poor quality or alignment of the original recording equipment, problems with the playback equipment, and lack of skills or lack of equipment.

1. Create a technical map of the collection in terms of tape brands, years, numbers, and ideally storage conditions. If this information is not readily available in an archive catalogue, then approximate numbers are sufficient, e.g. from visual inspection of shelves and estimation of the number of tapes per unit length.

2. Select a representative subset of the collection, for example 10 or more tapes from each brand/year combination. Transfer these tapes to see what problems occur. Use this to build an initial playability map for the collection. Compare this with the tables in this report.

3. Record the serial numbers for the tapes in the subset.

   a. If the serial numbers are all similar for a particular brand/year combination then those tapes are all likely to have the same chemical formulation and playability tables based on brand/year should be sufficient.

   b. If the serial numbers vary in structure for a particular brand/year then there may be a mix of formulations present. This means that playability tables based on groups of similarly structured serial numbers, i.e. chemical formulation, will provide a better playability map than brands/years.

4. If budget is available, then consider chemical analysis of one or two tapes from each group of tapes that have similar serial numbers. Use the results of the chemical analysis to identify binder breakdown and compare this with the playability problems that occurred during transfer. This can be used to build up a detailed playability map in terms of chemical groups rather than brands/years.

5. If the collection includes tapes that have spent a varying amount of time in the archive, or have been stored in other locations where the conditions are known, then look for correlations between playability, the time spent in the archive, and the storage environment. This will allow the effect of the environment to be determined and hence inform cost/benefit decisions on whether to improve the storage environment for tapes that won't be transferred or for tapes may be in the archive for several more years before transfer takes place.

6. Tape Playability Tables

6.1. How to interpret and use the tables

U-Matic can be classified as ‘difficult media’ because of the problems encountered during playback, for example when transferring the contents onto another carrier[9].

When transferring a collection of U-Matic tapes, care is needed to ensure efficient processes and workflows are used. This minimises costs and ensures the highest success rate and levels of quality will be achieved.

When a collection of media items needs to be transferred, PrestoSpace advocates a ‘Factory Approach’ where each of the steps in the workflow (selection, batching, inspection and assessment, preparation, transfer, quality control etc.) are done as separate and dedicated activities. Some of these steps, e.g. preparation and transfer, may need to be customised to address subsets of tapes, e.g. those that need cleaning, baking and digitisation using specialist players or by skilled operators. In this way, a digitisation project should be executed using a set of ‘transfer chains’, each of which is optimised for to work as smoothly and effectively as possible.

The key to the success of this approach is to ensure smooth running of each chain and to minimise the ‘exceptions’ that occur. Exceptions occur when an operator doesn’t have the particular skills or equipment needed to deal with a particular tape (e.g. because specialist cleaning techniques are required) or when an operator in a chain is faced with complicated decisions on what to do next (e.g. whether it is best to attempt a transfer multiple times or whether it is better to reassign the tape to a different chain that specialises in problematic media).

As described in the PrestoSpace report on difficult media (D5.3), when exceptions occur for less than 1% of items that pass through a chain, then the 'Exception' mechanism is very satisfying: operators have a consistent task to do, they get used to it, and they waste little effort addressing tasks they are not supposed to do. However, when exception rates rise to 10% or more, the operators have to take important decisions quite continuously, for example: Try again? Give up? Adjust? The effort spent in addressing difficult items rises quickly, especially when operators go outside their area of competence, which can easily result in the average cost of transferring items to double or more.

Knowing in advance what playability problems might occur during transfer can help considerably both when planning the transfer chains, setting up the exception handling policies, and then allocating individual items of media to the best suited chain when the project is being executed.

[9] PrestoSpace D5.3 describes difficult media as “as media for which migration to digital is not easy to automate. Within this category most are ‘open reel’ such as film under all its formats, video tapes and audio tapes, but there are also older media such as direct recording audio disks”.

We consider 10% to be the maximum exception rate for efficient operation of automated transfer chains using standard equipment and operators.

If more than 10% of tapes are expected to be problematic, then a triage step should be used in the workflow. Transfer chains involving specialist equipment, highly skilled operators and manual processes will probably be needed.

Successful transfer of problematic media, if possible at all, typically involves considerably more time and effort than media that is in good condition. The BBC estimates that it is five times more expensive to transfer an item of problematic media than it is to transfer one that plays back first time. Most of the extra cost is due to the need for skilled labour and extra time to transfer each item rather than the cost of specialist equipment. If 25% of the tapes in a collection are problematic then total transfer cost for the collection will at least double.

We estimate that 25% is the level of playability problems that will cause the cost of transferring a collection of tapes to double compared with ones that are all in good condition.

6.2. Playability tables for tape brands/years

This section contains a series of tape playability tables that show which problems occurred when INA U-Matic tapes were transferred by one of their service providers. The intention is that the tables can be used to 'lookup' the likelihood of a particular tape being problematic in advance of an attempt to transfer it. This is not to say that a specific tape will have a problem or not, only the probability that there will be a problem given what has been seen before for other tapes.

Figure 1 presents how often playability problems occurred for tapes made by different manufacturers. The purpose of this graph is to show which brands can be expected on average to cause more problems than others. The figures represent a range of manufacturing years and there can be significant variation between these years as shown in Table 1. Therefore, if information is also known on the year of manufacture for the tapes in a collection, then this should be used along with the tables below to get a better estimation of exactly which brands and years are likely to be most problematic.

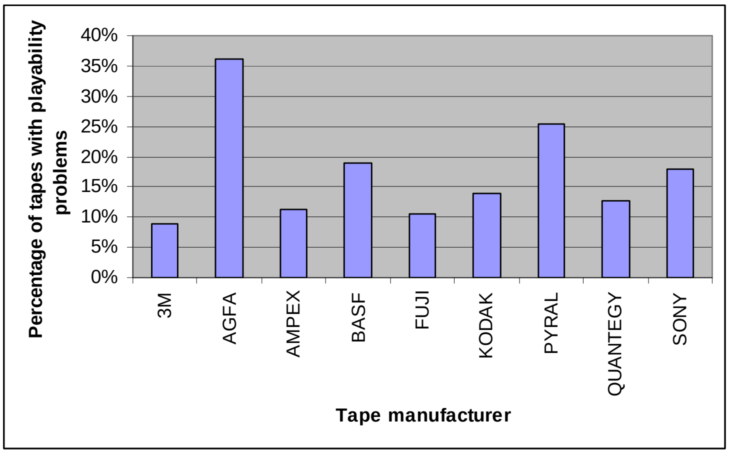

Figure 1 Percentage of tapes that had playability problems during transfer for different tape manufacturers

Table 1 to Table 4 provide more detail on which manufacturing years are more problematic than others and what type of playability problems can be expected. Each table has the following structure:

- The manufacturer of the tape is shown down the left hand side of the table.
- The year that the tape was first broadcast (diffusion year) is shown along the top of the table. This is indicative of the year that the tape was manufactured[10].
- Empty cells are where there are less than 20 tapes in the database for that particular combination of tape manufacturer and diffusion year[11].
- Green cells are where 10% or less of tapes showed playability problems when they were transferred.
- Orange cells are where between 10-25% of tapes showed playability problems. Transfer projects involving tapes in this category are likely to benefit from a triage step in the workflow and one or more specialised transfer chains.
- Red cells are where mor mthan mt5% 1(m)5(t)of mtapes lawyashility dmproblems. This level of problem will cause the costs of a transfer project to at least double compared with transferring tapes that are all in good condition.

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
3M	17	14	12	9	11	14	9	13	13	10	6	6	6	5	10	14
AGFA					43		51	67			42		60	40	14	0
AMPEX						34		14	17	20	12	9	10	8	8	0
BASF				13	23	3	21	41		9	11	19	14			
FUJI		15		5	24	49	13	3	8	8	11	12	17	9	8	
KODAK										20	23	17	12	3	3	
SONY	28	21	19	18	21	23	22	26	19	13	14	14	9	10	8	4

Table 1 At least one tape playability problem (head clogging, sticky tape, need to replay)

[10] As is common with databases held by many AV archives, the date of media manufacture is not available in the INA database. The only information that is available is the date that the content recorded on the tape was first broadcast ('diffusion date' to use INA terminology). The manufacturing date and the broadcast date are likely to be quite close together (the same year, or perhaps the following year). Broadcast masters are typically recorded on freshly manufactured and previously unused tapes. The timescales of the production process means that there isn't a large delay between recording and broadcast. U-Matic tapes are not typically 'stockpiled' for long periods of time at any point in the supply chain between manufacturer and broadcaster, e.g. within distributors and hence the time from factory to recorder is relatively short. Therefore, the diffusion date for a tape can be considered as indicative of the original manufacturing date.

[11] For less than 20 tapes the effects of statistical fluctuations can be very large which means it is dangerous to rely on the table to provide any form of prediction on what is likely to happen when attempting to transfer a tape.

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
3M	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
AGFA					8		0	2			2		0	0	0	0
AMPEX						0		1	1	1	0	0	0	0	0	0
BASF				0	0	0	0	1		0	0	0	0			
FUJI		0		0	0	0	0	0	0	0	1	0	0	0	0	
KODAK										0	0	0	0	0	0	
SONY	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2 U-Matic tapes that needed to be replayed more than once during transfer

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
3M	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
AGFA					0		10	10			0		28	12		

Once the chemical group has been identified, the likelihood of playability problems occurring for that group can be looked up in the tables below. Unfortunately, the serial number was not recorded as a matter of course for all the tape transfers in the INA database. As a result, INA have gone back to the original media in their archives and manually recorded the serial number for approximately 1000 tapes. Although the emphasis of the subset is on problematic tapes, this is still a small fraction of the total INA tape transfer database and playability statistics are not available for all of the 44 different chemical groups identified by CRCC.

Table 5 provides a playability rating for chemical groups where there were enough tapes in the database to draw statistically meaningful conclusions. A 'green' rating is given to chemical groups that show relatively few playability problems (approximately 10% or less). A 'red' rating is given to chemical groups that show a relatively high number of playability problems (approximately 25% or more). An 'orange' rating is given to tapes that have playability characteristics somewhere in-between. The colour coding can be compared directly with that used for the brand/year playability problem tables in Section 6.2.

A numerical playability problem rating is also given on a scale of 1 – 9. Tapes with a high playability problem rating showed problems more frequently when transferred.

Manufacturer	Chemical Group ID	Playability Problem Rating
AGFA	AGF5	9
AGFA	AGF4	6
SONY	S8	4
AGFA	AGF3	4
AGFA	AGF2	4
SONY	S7	3
SONY	S6	3
AMPEX	APX2	3
SONY	S5	2
AMPEX	APX1	1
SONY	S1	1
SONY	S12	1
FUJI	FJ1	0
SONY	S2	0
SONY	S13	0

Table 5 Playability problem rating for different chemical groups based on observed playability problems. A 'green' rating means that playability problems occurred at half as often as the average or less. A 'red' rating means that playability problems occurred at least twice as often as the average. The 'orange' rating is in-between the red and the green, i.e. the number of tapes with playability problems was around average.

The results in Table 5 are based on the observed playability problems during U-Matic tape transfers. Chemical analysis of example tapes from each chemical group has also been used to look for evidence of degradation. This can be used to predict which of the chemical groups are most likely to cause playability problems.

As described in Appendix D: Problems encountered during U-Matic tape transfer, some tape binders are more susceptible to fast deterioration than others. Adipic acid plays a major role in the degradation process for these susceptible binders. CRCC analysed 29 tapes from various chemical groups to look for the presence of adipic acid. The database of U-Matic tape transfers was then analysed to see if playability problems occurred more frequently when a tape belonged to a chemical group where CRCC has detected the presence of adipic acid.

If adipic acid is present in the chemical composition of a tape, then on average the tape is 3 times more likely to have playability problems during transfer[12].

CRCC also used chromatography to look at the distribution of molecular weights for the different chemicals components present in the binder. When hydrolysis takes place, long polymer chains in the binder break down into shorter fragments. This is seen in the chromatography results as a lower average molecular weight.

The average molecular weight for binder components in tapes from 5 different chemical groups (S6, S7, S8, AGF4, APX1) was compared to the occurrence of playability problems for these chemical groups. All tapes contained adipic acid. The results (see Appendix D: Problems encountered during U-Matic tape transfer) show a clear correlation. A higher occurrence of playability problems is seen for the chemical groups that have a lower average molecular weight for binder components (i.e. a higher level of binder breakdown).

The more binder breakdown in a tape, then the more likely it is that that the tape will have playability problems.

This correlation is used below to predict a 'playability problem rating' for each chemical that underwent chemical analysis by CRCC. This is shown in Table 6. The colour coding and scale is the same as Table 5, i.e. groups labelled as 'green' are those where 10% or less of tapes are predicted to show playability problems, 'red' is where 25% or more of tapes are predicted to show playability problems, and 'orange' is in-between.

The average molecular weight of binder components can also be used to predict the playability of tapes with binders that don't contain adipic acid. This is shown in Table 7. This table shows that some tape formulations that don't produce adipic acid when they degrade are also likely to cause significant playability problems. However, it is also clear from comparing Table 6 and Table 7 that tape formulations that do produce adipic acid when they degrade tend to be more susceptible to tape playability problems than those that don't. For the FUJI FJ1 group, there are enough tapes in the database to compare the predictions with observed level of playability problems. Only 2 out of the 51 tapes identified as FJ1 from their serial

12 There were 494 tapes where the serial number was available, the chemical group could be identified and lab analysis had been done for that group. 63 belonged to Group IDs with no adipic acid, and 431 tapes belonged to Group IDs that do have adipic acid. Of the 63 tapes that don't have adipic acid, only 10% showed playability problems. In contrast, 34% of the tapes that do have adipic acid also showed playability problems. When looking at the tapes explicitly marked by transfer operators as causing head clogging, only 6% of tapes with no adipic acid caused head-clogging, compared to 27% of tapes that did have adipic acid.

numbers had playability problems. This matches the prediction in Table 7 that FJ1 has very good playability.

Manufacturer	Chemical Group ID	Adipic Acid	Predicted Playability Problem Rating
AGFA	AGF1	Yes	6
AGFA	AGF4	Yes	6
FUJI	FJ4	Yes	5
BASF	BSF2	Yes	5
AGFA	AGF6	Yes	4
AGFA	AGF1	Yes	4
KODAK	Kodak	Yes	4
SONY	S7	Yes	4
SONY	S8	Yes	4
BASF	BSF3	Yes	3
SONY	S6	Yes	3
AMPEX	APX5	Yes	3
AMPEX	APX4	Yes	3
AMPEX	APX5	Yes	3
QUANTEGY	Quant	Yes	2
AMPEX	APX1	Yes	1

Table 6 Predicted playability problem rating for chemical groups that are known to contain adipic acid. The scale and the colour coding is the same as for Table 5.

Manufacturer	Chemical Group ID	Adipic Acid	Predicted Playability Problem Rating
3M	3M3	No	6
3M	3M6	No	4
3M	3M2	No	4
3M	3M1	No	3
3M	3M4	No	3
SONY	S4	No	3
AGFA	AGF7	No	3
SONY	S10	No	2
SONY	S3	No	2
FUJI	FJ2	No	2
SONY	S9	No	1
FUJI	FJ1	No	1

Table 7 Predicted playability problem rating for chemical groups that are known not to contain adipic acid. The scale and the colour coding is the same as for Table 5

Note that in the tables above, a couple of chemical groups appear more than once in the table, e.g. AMPX5 and AGF1 in Table 6. This is a result of two tapes from the same chemical group but different years of manufacture having undergone laboratory analysis. This shows that there is some variation between tapes even with the same chemical group. Therefore, when using the tables above for estimating whether problems will occur for a particular tape, it should be remembered that there is very likely to be variations on a tape by tape basis from the predictions. The 1000 tapes where the serial number is known were analysed to identify any correlation between chemical group and year of manufacture. As a large number of tapes were from SONY (over 500), this was possible for several of the SONY groups. The results are shown in Figure 2. Most years are dominated by a single chemical group (e.g. SONY tapes in the database from 1980 are almost entirely S8). Each chemical group is typically seen for several consecutive years (e.g. S6 is the dominant chemical group for SONY tapes between 1982 and 1984). This would be consistent with SONY changing their tape formulation every few years and only using one formulation at any one time. The exception is 1986 and1987 where several different chemical groups appear together before a transition to S12 as the dominant group starting in 1988.

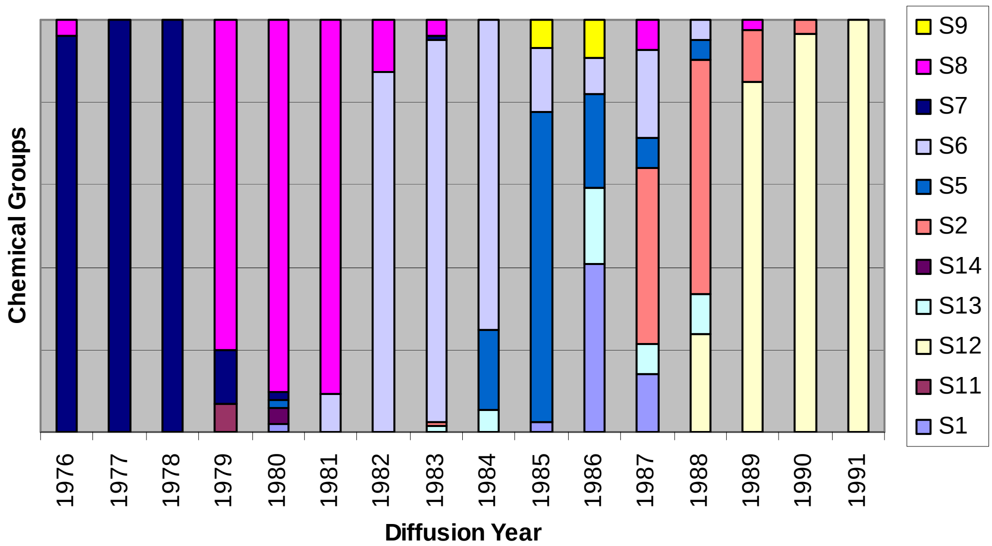

Figure 2 Distribution of SONY chemical groups across diffusion years

The correlation between chemical group and year of manufacture can be used to compare the playability problems predicted in this section with the playability problems observed in the large INA database of tape transfers presented in Section 6.2. The predictions based on chemical groups are broadly in agreement with what is observed for SONY tapes year by year in Table 1

	Year												
Group	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1989	1990	1991
S12													
S2													
S5													
S6													
S7													
S8													

Table 8 Correlation between chemical group and diffusion year for SONY tapes. Cells are filled where 75% or more of tapes for a particular year belong to the group shown. Colours correspond to the predicted playability of the group.

6.4. Effect of archive storage environment

Tape playability problems arise at least in part due to chemical decomposition of the tape binder. The rate of this chemical reaction is dependent on both the temperature and humidity of the environment in which tapes are stored. The rate of degradation is directly proportional to humidity and is exponential with temperature. Therefore, tapes, as with other media that suffer chemical degradation such as film and photographs, are best stored in cool dry conditions, e.g. as advised by AMIA[13] and the Image Permanence Institute[14].

The rate at which degradation takes place can vary significantly depending on the exact chemical processes taking place. Therefore, there is no universal rule for magnetic tape that says, for example 'if you store your tapes at 20 °C and 30% relative humidity then they will last for 50 years'. The lifetime of tapes due to storage environment will depend strongly on the tape formulation and hence the brand and year of manufacture as discussed already in this report.

An investigation of the effect of storage environment on the INA U-Matic tapes is presented below in Figure 3. The analysis is hampered by not knowing the exact history of the tapes in the database and hence the environment in which they have been kept. Therefore, the analysis is limited to looking for a simple correlation between the time spent in the archive and the degree of degradation of the tapes on average.

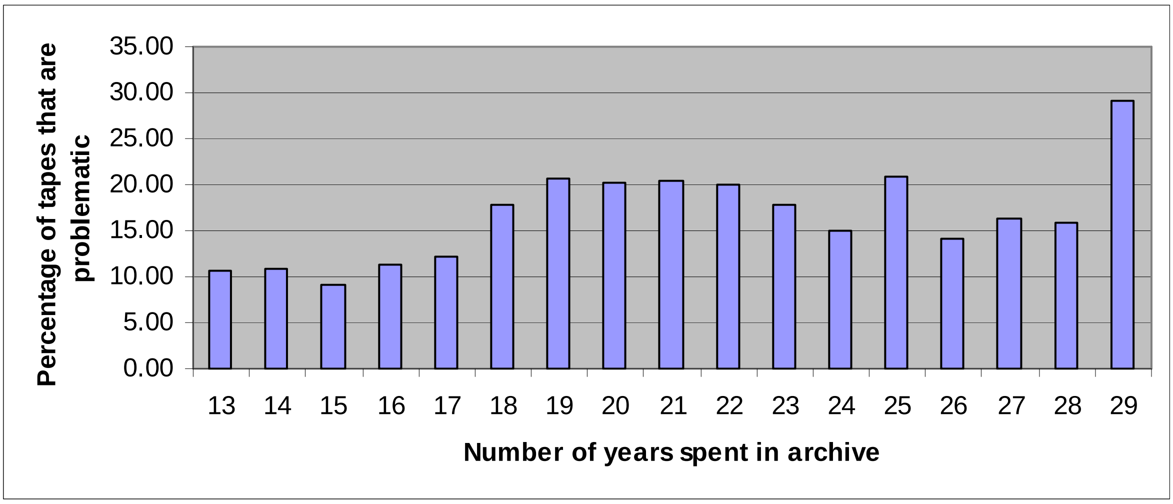

Figure 3 Percentage of tapes causing playability problems (all brands and diffusion years) as a function of how long the tapes have been in the archive (time between the year of manufacture and the year of digitisation).

It can be seen from Figure 3 that there is a small positive correlation between the time tapes have spent in the archive and the fraction of those tapes with playability problems. This is a relatively small effect, especially considering that the tapes that have spent the most time in the archive are those manufactured in the early days of U-Matic when tape formulations were not as well developed as they are today. It

13 http://www.amianet.org/resources/guides/storage_standards.pdf
14 http://www.imagepermanenceinstitute.org/index.html

should also be noted that the storage conditions in the INA archive are temperature and humidity controlled and hence the effect of the storage environment on degradation has been deliberately minimised. This is in contrast to other archives which do not use controlled storage environments where a higher degree of U-Matic tape playability problems are seen[15].

15 The BBC do not use climate control in their archive and their U-Matic tapes have been subject to prevailing temperature and humidity conditions, including seasonal variations. The BBC have recently completed transfer of 57,000 U-Matic tapes covering a variety of tape manufacturing brands and years. 40% would not playback first time in contrast to approx 20% for INA. Whilst not enough information is available for the BBC tape transfers to say categorically that the increased number of playability problems is a result of the storage environment, it is at least likely that this is the cause.

7. Conclusions

Quantitative information on tape transfer problems is valuable when planning and executing U-Matic tape transfer projects. The same information is useful more generally when assessing the condition of a U-Matic tape collection and risk of loss if preservation or digitisation action is not taken.

U-Matic tapes are classed as 'difficult media' and are a subject to a range of problems when attempts are made to transfer them into digital form. These problems include lack of equipment and skilled operators, chemical degradation, wear and tear, mould, dirt, and poor recording quality.

This report has investigated the playability problems (head clogging, sticky tapes, need to replay the tape multiple times) that arose during the transfer of approximately 50,000 U-Matic tapes from the INA archive. The main findings are:

- Playability problems vary significantly between manufacturers and depend on when the tapes were made. Tapes from some brand/year combinations showed playability problems that occurred 10 times more often than others.

- Playability problems are directly related to the chemical breakdown of the tape binder layer through a hydrolysis process and this can be measured through laboratory analysis.

- The rate of breakdown of a tape binder layer depends strongly on the exact chemical formulation of a tape and this varies between manufacturers and production years.

- Playability problems occur more often when the chemical breakdown process has had longer to take place and hence more breakdown has occurred. However, this is secondary in scale to the variations between different tape formulations.

- Tape playability tables provide a useful way to estimate the costs of a U-Matic tape transfer project and to decide how to structure the transfer process, e.g. by including triage and using specialised transfer chains to deal with particularly problematic tapes.

There is still plenty of further work that could be done to extend this report. This includes: (a) extending the comparison of lab analysis results with observed playability problems by widening the number of chemical groups and by looking at other factors, e.g. back-coating, formulation of the magnetic layer, and tribological properties such as abrasiveness; (b) more analysis of the effect of storage environment by looking at playability problems in a range of archive environments and comparing this to accelerated ageing studies done in the laboratory; and (c) use of machine learning techniques in software tools to automatically and better classify serial numbers into different chemical groups.

Appendix A: Archive holdings of U-Matic

To understand the scale and widespread use of U-Matic, it is worth looking at some of the recent surveys into holdings of AV archives across Europe and the World.

The IASA 2003 survey into endangered audiovisual carriers [16] identified 31 distinct types of content held in the 118 organisations worldwide that responded to the survey it issued. U-Matic was second only to VHS as the most commonly held video format in these AV archives.

The EC PRESTO project [17] surveyed 10 broadcast archives in 2000 and found about 5 million hours of AV material which included over 940,000 U-Matic tapes.

The EC PrestoSpace Project[18]conducted a more comprehensive survey in 2004 that covered 20 broadcast and film archives from across Europe[19] Whilst the total amount of U-Matic tapes had decreased since the PRESTO survey (mostly due to ongoing digitisation projects by the major broadcast archives in Europe) there were still almost 700,000 U-Matic tapes on archive shelves at that time.

In contrast to PRESTO and PrestoSpace that surveyed large broadcast and film archives, the TAPE project [20] 2005 survey of European AV archives received responses from almost 400 organisations that can be classified as mostly small archives (over 75% of the respondents have video collections of 5000 hrs or less). Over 25% of respondents have U-Matic in their collections, although this is often small in comparison to holdings of VHS, Betacam or DigiBeta.

The findings of TAPE are echoed by the SEMLAC[21] survey in the South East of England [22] that identified 228 archives [23] in this region alone. The majority of the content holders in the SEMLAC survey can be classed as 'small' having less than 1000 items. 15% of SEMLAC respondents hold professional analogue formats including U-Matic.

An overall figure for the volume of AV content worldwide was estimated by UNESCO to be 200 Million hours in 2002 [24]. PRESTO estimated the European total of

[16] Survey of Endangered Audiovisual Carriers: http://portal.unesco.org/ci/en/ev.php-URL_ID=13437&URL_DO=DO_TOPIC&URL_SECTION=201.html

[17] PRESTO Project homepage: http://presto.joanneum.ac.at/index.asp

[18] PrestoSpace project homepage: http://www.prestospace.org/

[19] PrestoSpace user survey: "Deliverable 2.1 User Requirements Final Report" http://www.prestospace.org/project/public.en.html

[20] TAPE: http://www.tape-online.net/

[21] South East Museums Archives and Libraries Council (SEMLAC) http://www.semlac.org/

[22] http://www.semlac.org/archives7.html

[23] http://www.semlac.org/docs/archive%20docs/av_finalreportdir.pdf

[24] UNESCO estimate of AV content worldwide: http://portal.unesco.org/ci/en/ev.php-URL_ID=2034&URL_DO=DO_TOPIC&URL_SECTION=201.html

broadcast material to be 10 times higher than that found in its survey, i.e. 50 million hours [25].

We estimate that the total number of U-Matic tapes in Europe is still well over one million[26] in 2007.

[25] "Archive Preservation and Exploitation Requirements". Deliverable D2 of the PRESTO project. http://presto.joanneum.ac.at/projects.asp

[26] 700,000 U-Matic tapes were found in 2004 in the PrestoSpace survey. This number will have now fallen. However this doesn't include the U-Matics in small archives and the PrestoSpace survey certainly doesn't cover all the large archives in Europe. Therefore, applying some multipliers gives a conservative figure of 1 million U-Matic still remaining.

Appendix B: U-Matic problems found by archives

U-Matic tapes suffer from a range of problems and, as shown by the results of the IASA2003[27] survey in Figure 4, more U-Matic tapes are decaying or giving more cause for concern than any other video format. This includes earlier open reel formats such as 2 inch and 1 inch tape.

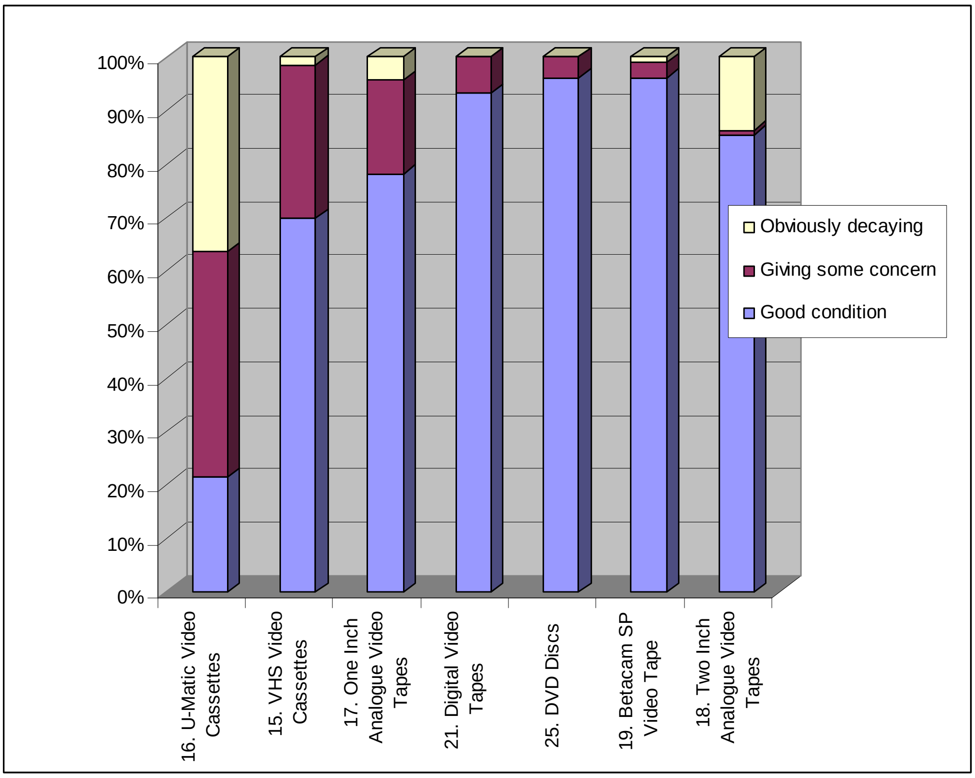

Figure 4 IASA 2003 survey results for the condition of material on the major video formats. The formats are ordered by the percentage of items in a particular format that are 'giving some cause for concern'.

The findings of the IASA survey are also seen in the results of the TAPE survey as shown in Figure 5.

Somewhere between 30% and 80% of all U-Matic tapes are showing obvious signs of decay or are giving the archives holding them cause for concern[28].

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[27] Survey of Endangered Audiovisual Carriers: http://portal.unesco.org/ci/en/ev.php-URL_ID=13437&URL_DO=DO_TOPIC&URL_SECTION=201.html

[28] Estimates vary from the self assessment of TAPE archives that believe that 70% of content is in good condition to the reverse analysis of the TAPE results by PrestoSpace that estimates 80% of the material may have problems. The TAPE survey also revealed that only 15% of respondants have a combination of climate control, trained staff and a preservation programme, so the TAPE self-assessment is likely to be an underestimate of the real extent of problems with U-Matic.

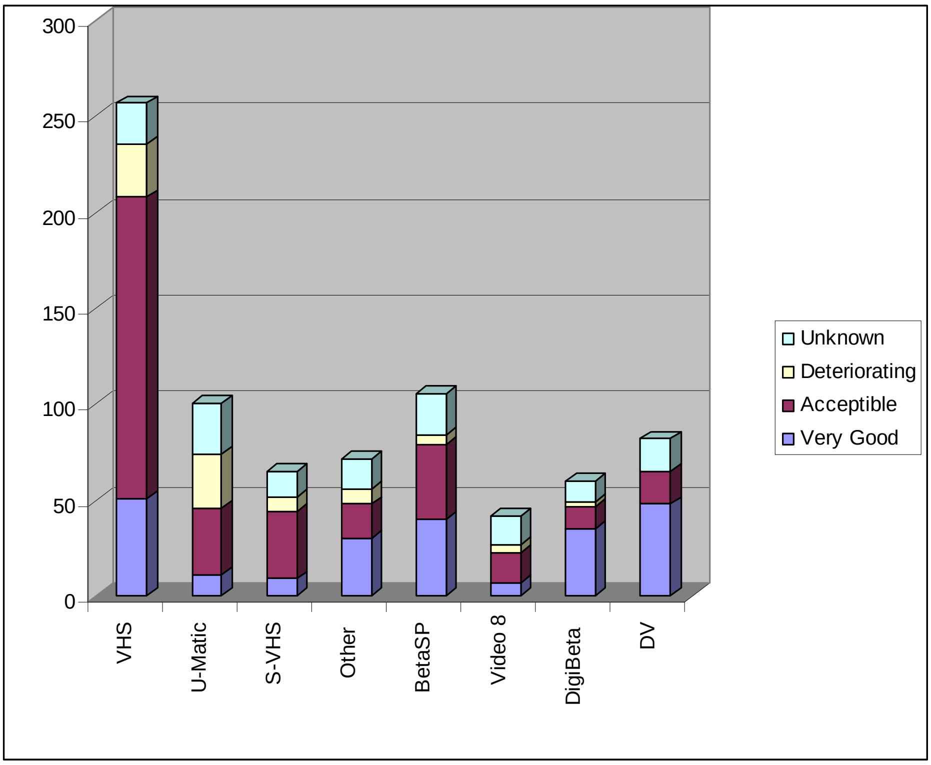

Figure 5 TAPE survey results for the number of survey respondents with video content in a particular condition and format. The formats are ordered in terms of the number of survey respondents that have items in that format that they consider to be deteriorating.

This is reflected in and the preservation priorities attached to different video formats by the archives surveyed in PrestoSpace as shown in Figure 6, which clearly demonstrates that:

U-Matic is widely considered as the top priority for video preservation by the major broadcast archives in Europe.

11 of 16 archives reporting

Preservation Priority Rating: Video	
1,9	¾" Umatic H PAL
1,4	¾" Umatic LB PAL
1,3	1 inch C PAL
1,3	1 inch B PAL
1,0	¾" UmaticLB SECAM
0,7	2inch PAL
0,6	BETACAM SP
0,6	D3
0,6	¾" Umatic H SECAM
0,6	¾" Umatic SP PAL
0,6	¾" Umatic (other standard, eg NTSC)
0,4	2 inch B/W
0,3	½ inch BETACAM
0,1	½ inch MII
0,1	VHS

Figure 6 PrestoSpace survey results on the priorities for video preservation.

Appendix D: Problems encountered during U-Matic tape transfer

Plenty of information is available on the generic problems with tape based media. For example, the AMIA video tape preservation factsheets[29] provide an excellent guide to the problems that may be encountered with video tape. U-Matic tapes suffer from many of these problems. Much more limited information is available on exactly which problems are most likely to occur for U-Matic. For example, the Texas Commission on the Arts have the following in their Videotape Identification and Assessment Guide[30].

> *"Older 3/4" U-Matic tapes, such as those from the 1970s and 1980s, are at great risk of signal loss due to problems with the physical material. Newer tapes may be in better shape, but hardware and media obsolescence is still a major issue".*

Even the PrestoSpace report on difficult media simply states:

> *"3/4 U-Matic/BVU:. Reliable VCR - Operation very dependant on tape quality (All Agfa and some Sony batches)".*

As with most tape based AV media, there are a range of problems that may be encountered when playing back U-Matic tapes. These include:

- Obsolete and hard to obtain playback equipment
- Lack of necessary skills or need for specialised equipment, e.g. cleaners
- Decay of the media, e.g. due to chemical decomposition
- Dirt, dust, mould or other forms of tape contamination that can come from everyday use, poor storage conditions, or disasters such as fire or flooding.
- Wear and tear or other forms of damage to the tape due to use or mishandling both in the production and archive environments.
- Poor quality signal due to the way the original recording was made, e.g. due to head misalignment, worn pinch rollers, dirt on the tape or heads.
- Damaged cassettes
- Difficulty in identifying the content, e.g. due to lack of cataloguing

[29] AMIA Video Tape Preservation Factsheet
http://www.amianet.org/publication/resources/guidelines/videofacts/commonprobs.html

[30] http://www.arts.state.tx.us/video/

Some of these are playability problems that are result of the inherent chemical and tribological properties of the materials used for the tape itself. For example, hydrolysis of the tape binder layer (the 'glue' between the magnetic oxide coating and the tape substrate) can cause a range of problems during playback. These include:

- 'sticky' tapes where the tape sticks to itself and the tape player transport components (rollers, guides, heads), which gives irregular playback speed or at the extreme causes the tape to jam in the transport or even snap.

- Head clogging where some of the material from the tape detaches and 'clogs up' the tape heads causing loss of signal, sometimes generating a 'squealing' sound from the transport, and resulting in the need for head cleaning.

- Shedding, which is an extreme case of hydrolysis where whole areas of the oxide layer completely detach leaving only the backing behind. In these cases affected areas can appear transparent as none of the oxide layer remains.

Of the layers in U-Matic tape (back coat, substrate, topcoat), the binder part of the top coat layer is the 'weakest link' when it comes to tape playability.

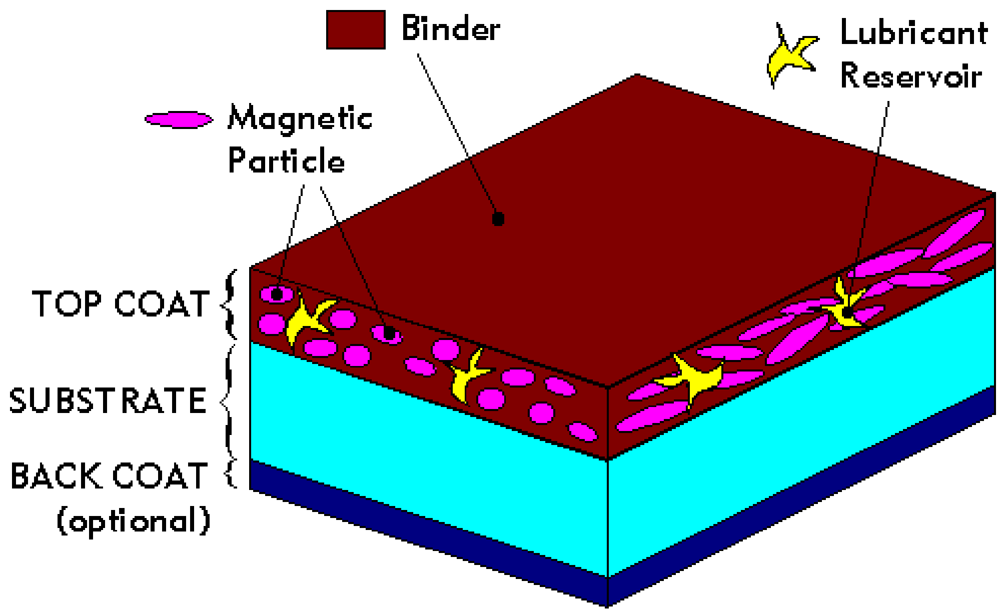

Figure 7 Diagram of the layers in magnetic tape (reproduced from Van Bogart's guide to Magnetic Tape Storage and Handling http://www.clir.org/pubs/reports/pub54/2what_wrong.html)

The substrate is typically made of polyester and is relatively stable. The backcoat is a simple coating on the reverse of the base layer to help remove friction. The oxide part of the topcoat layer consists of the magnetic particles that whilst this might suffer from demagnetisation over time, it is relatively stable. The binder on the other hand contains a complex mix of chemicals including adhesives to bind the oxide to the substrate layer, lubricants to ensure smooth playback, cleaning agents to keep playback heads free of debris, and antistatic agents to reduce static build-up. Problems can include loss of lubricant (a natural process when tapes are repeatedly played, or as a result of degradation or migration of the lubricant), abrasive tape formulations (originally designed by manufacturers as a way of improving tape playability by keeping the heads clean but with the side effect of causing faster head wear) causing head wear, migration of chemical components between tape layers onto the tape surface (e.g. causing white powdery or crystalline deposits that cause signal loss), and structural degradation causing dimensional changes such as stretching or increased likelihood of breakage.

The connection between underlying chemical, mechanical or tribological problems and observed playability problems can be complex.

- More than one underlying cause can result in the same observed effect. For example, loss of lubricant or binder hydrolysis can both result in tapes sticking in a player. Tape deterioration, dirt, and misaligned equipment can all result in loss of signal.

- Problems may also be exacerbated by the environment in which tapes have been stored. For example, high temperature and humidity in the archive will accelerate chemical decomposition processes. If the dimensional stability of the tape starts to degrade and the tape is stored in an environment that is not climate controlled then stresses will build up in the tape pack and this can distort the tape and cause tracking errors on playback (which is why current wisdom is to rewind tapes periodically, e.g. every couple of years even if they are not played).

- Problems may be reduced by choice of climate when playing back the tapes. For example, sticky tapes will tend to stick less if they are played back in cool dry conditions after proper acclimatisation. However, they can also cause more hear wear.

- Some problems can be addressed through treatments such as cleaning, baking, adjustments to playback equipment, or signal processing, for example the use of time base correctors or dropout compensators.

The extent to which playability problems will occur when transferring a collection of U-Matic tapes will depend on strongly on the particular formulation of the tape, which in turn depends on the manufacturer and specific batch, the archive environment in which the tapes have been stored, and the specific treatments and equipment used during transfer.

Some of the problems seen when playing back tapes are due to imperfect recording or the introduction of damage or dirt when the tape has been subsequently used or stored. For example, dropouts (loss of signal for a short period of time, e.g. a single video line) are common place with U-Matic (Over 80% of INA tapes showed dropouts to some extent irrespective of brand and age) and can come from dirt temporarily separating the tape from the head or temporarily clogging the head for a revolution, poor alignment of heads during recording, worn heads on the playback machine, or small areas of defects or damage to the tape surface. Lack of maintenance of playback equipment can also cause problems, e.g. because tape heads become worn and hence rough and then cause material to the worn away from the tape which in turn clogs up the heads. Pinch rollers can become worn which in turn can push the tape up or down the guides posts so it becomes curled when it is forced against the stops. These problems are not inherent problems of U-Matic tape per se but result from the way the tape has been recorded, stored, handled or played back.

Full details of the problems that can occur can be found in other PrestoSpace deliverables and websites including:

- Report on video and audio tape deterioration mechanisms (D6.1)
- Automation of difficult media, the PrestoSpace (D5.3)
- Annual Reports on Preservation Issues for European Audiovisual Collections (D22.4, D22.6 and D22.8)
- PrestoSpace preservation and digitisation web site http://prestospace-sam.ssl.co.uk/
- PrestoSpace online database of AV formats http://prestospace.it-innovation.soton.ac.uk/

There is also plenty of information on tape problems, handling and storage practices, and corrective treatments available from the following:

- Van Bogart's 1995 guide to Magnetic Tape Storage and Handling[31].
- AMIA fact sheets[32] [33], including Lindner and Wheeler's 'Q&A' on video tape[34].
- Video interchange guide[35]

This report focuses specifically on tape playability problems that arise as a result of the formulations used for U-Matic tapes.

31 http://www.clir.org/pubs/reports/pub54/
32 http://www.amianet.org/resources/guides/WheelerVideo.pdf
33 http://www.amianet.org/resources/guides/WheelerVideo.pdf
34 http://www.amianet.org/resources/guides/video_q&a.pdf
35 http://www.videointerchange.com/

Appendix E: Converting serial numbers to chemical groups

	Update date :		29-Jun-06							
Group	**Position code**	**length**	**param 1**	**param 2**	**param 3**	**Manufacturer**	**SN reading**	**First**	**Last**	**SN example**
APX1	12	14	"N..."	other		AMPEX	?	1981	?	N3196857012166
APX2	12	14	"N..."	"...000000.."		AMPEX	?	1984	?	N0424000000006
APX3	10	5	yellow			AMPEX	ABCDE : 199A ; day BCD ; prod. line E	1990	?	10571 187 kca-30
APX4	10	5	white			AMPEX	ABCDE : 199A ; day BCD ; prod. line E	1990	?	31261 187 kca-30
APX5	11	4	blue			AMPEX	ABCD : 198A ; week BC ; prod. line D	1986	1989	6818
APX6	10	4	Yellow			AMPEX	?	1991	?	9110 197 bca-60
S1	9	7	"51..."	other "…X0X"	white / black cassette	SONY	51XXAXB : 0B/198A ; P=dec, M = nov, S = oct	1984	1987	5190505
S2	9	7	"51..."	".….A8M"	white	SONY	51XXA8B : 0B/198A ; P=dec, M = nov, S = oct	1987	?	5181787
S3	9	7	"51..."	".….A4M"	other SN on the side "xx xxx xxx/xxx xx"	SONY/BASF	(code sony) 51XXA4B : 0B/198A ; P=dec, M = nov, S = oct	1987	1987	5111746
S4	9	11	"A…."	white	"……X/X"	SONY	AXXXXXBC X/X : 0C/199B	1993	1993	A1813233 P/S
S5	7	8	"Letter21…."	white		SONY	LXXXXXAB :	1981	1982	E2103424

							0B/198A			
S6	9	7	"21…."	white		SONY	2XXXAXB : 0B/198A	1980	1984	216112P
S7	9	6	"2..."	black		SONY	2XXAXB : 0B/197A ; P=dec, M=nov S = oct	1978	1980	242813
S7'	9	6	"2..."	black		SONY	2XXABB : BB/197(5+A)	1975	1978	222005
S8	9	6	"A..."	black		SONY	AXXBCC : CC/19(7)(8)B	1978	1982	A20810
S8'	9	7	"-A…."	black		SONY	-AXXBCC : CC/19(7)(8)B	1979	1981	-A14902
S9	9	7	"81..."	"….A0M"		SONY	81XXAXB : 0B/198A ; P=dec, M = nov, S = oct	1988	1990	8190505
S10	9	7	"51…"	"…..A4M"	white	SONY	(code sony) 51XXA4B : 0B/198A ; P=dec, M = nov, S = oct			
S11	9	11	"63LXXXDEXXL"	sticker		SONY		1979	1979	63E850DE11B
S11	9	12	"63LXXXDEXXLX"	sticker		SONY		1979	1979	63E850DE03A10
S11	9	13	"63LXXXDEXXLXX"	sticker		SONY		1979	1979	63P901DE26C22
S12	9	7	"81…"	"….A8M"	white	SONY	81XXAXB : 0B/199A (ou 198A); P=dec, M = nov, S = oct			8191086
S13	9	7	"51..."	other "…X0X"	white / gray cassette	SONY	51XXAXB : 0B/198A ; P=dec, M = nov, S = oct	1984	1987	5190505
S14	9	7	"81…"	other "…X1X"						
AGF1	6	10	"H..."	black on sticker		AGFA	HA…. : 198A	1987	1993	H71.0421.26

AGF2	6	5	"20…"	blue on sticker	symboles facultatifs	AGFA	probably all 1980	1980	1983	20474
AGF3	6	8	"20…"	blue on sticker		AGFA	probably all 1980	1980	1983	20148132
AGF4	6	8	"28…"	blue on sticker		AGFA	probably all 1982	1982	1983	28627119
AGF5	6	8	"29…"	blue on sticker		AGFA	probably all 1982	1983	?	29690110
AGF6	6	10	"B…"	black on sticker		AGFA	BA… : 198A	1988	1990	b84.00391.25
AGF7	7	10	yellow			AGFA	?	1990	1992	9215205533
BSF1	6	15	"XX XXX XXX/XXX XXX"	"XX inf/eq 17"		BASF				
BSF1	6	14	"XX XXX XXX/XXX XX"	"XX inf/eq 17"		BASF				
BSF1	6	13	"XX XXX XXX/XXX X"	"XX inf/eq 17"		BASF				
BSF1	6	12	"XX XXX XXX/XXX"	"XX inf/eq 17"		BASF				
BSF2	14	15	"XX XXX XXX/XXX XXX"	"XX inf/eq 17"		BASF				
BSF2	14	14	"XX XXX XXX/XXX XX"	"XX sup/eq 18"		BASF				
BSF2	14	13	"XX XXX XXX/XXX X"	"XX sup/eq 18"		BASF				
BSF2	14	12	"XX XXX XXX/XXX"	"XX sup/eq 18"		BASF				
S3	14	12	"XX XXX XXX/XXX"	other SN on the backside "51….X4X"		SONY/BASF	(Sony SN) 51XXA4B : 0B/198A ; P=dec, M = nov, S = oct	1987	1987	5111746
BSF3	6	11	"letter…"			BASF				T920A J 13 828
FJ1	9	13	"CV…"			FUJI	probably "CVABB…-XX" BB/197(8)A"	1978	1982	CV10414515-60

							XX tape length			
FJ2	8	8	"XXLLLXXX" stamp			FUJI	probably "XXLLLA…" 198A" XX DUREE E,V,	1982	1983	60VAL109
FJ3	8	8	"XXLLLXXX" printed	Large font (flap)	no backcoating	FUJI	probably "XXLLLA…" 198A" XX DUREE F,I	1984	1987	60IBC610
FJ4	8	8	"XXLLLXXX" printed	Thin font (flat)		FUJI	probably "XXLLLA…" 198A" XX DUREE L,N	1986	1991	60LEF817
FJ5	8	8	"XXLLLXXX" printed	Large font (flap)	backcoated	FUJI	probably "XXLLLA…" 198A" XX DUREE L,N			60IBC610
3M1	13	12	"XXXXX XX XXX XX"	5 digits in 11		3M	"XXXXX…" increasing "17000" 1976, "20000" 1978, "40000" 1981, "46000" 1984, "50000" 1989	1976	1982	17218 15 004 24
3M1	13	13	"XXXXX XX XXXX XX"	5 digits in 11		3M		1981	1981	40481 16 0110 11
3M2	13	5	"XXXXX"			3M	"XXXXX…" increasing "17000" 1976, "20000" 1978, "40000" 1981, "46000" 1984, "50000" 1991	1982	1982	42416
3M3	11	10	"XXXXX XXXXX"	red		3M	"...XXXXX" increasing "17000" 1976, "20000" 1978, "40000" 1981, "46000" 1984,	1984	1989	8327446493

							"50000" 1992			
3M4	11	7	"XXXXXXX"	red		3M	?	1987	1989	6227305
3M5	7	12	"XXXXXXXXXXXX"	yellow		3M	?	1990		620820783999
3M6	13	11	"XXXXX XX XXX X"			3M	"XXXXX…" increasing "17000" 1976, "20000" 1978, "40000" 1981, "46000" 1984, "50000" 1990	1976	1982	24074 01 004 8
3M6	13	12	"XXXXX XX XXX XX"			3M	"XXXXX…" increasing "17000" 1976, "20000" 1978, "40000" 1981, "46000" 1984, "50000" 1990			24043 01 006 10

Appendix F: Analysis Method

The conclusions of this report are drawn from the analysis of a database of operator contaminants from the environment and is not an intrinsic function of the playability of the tape itself.

The overall population of the database is shown in Figure 8. This shows the year of digitisation, the year of diffusion, and the total number of tapes for each digitisation-diffusion year combination.

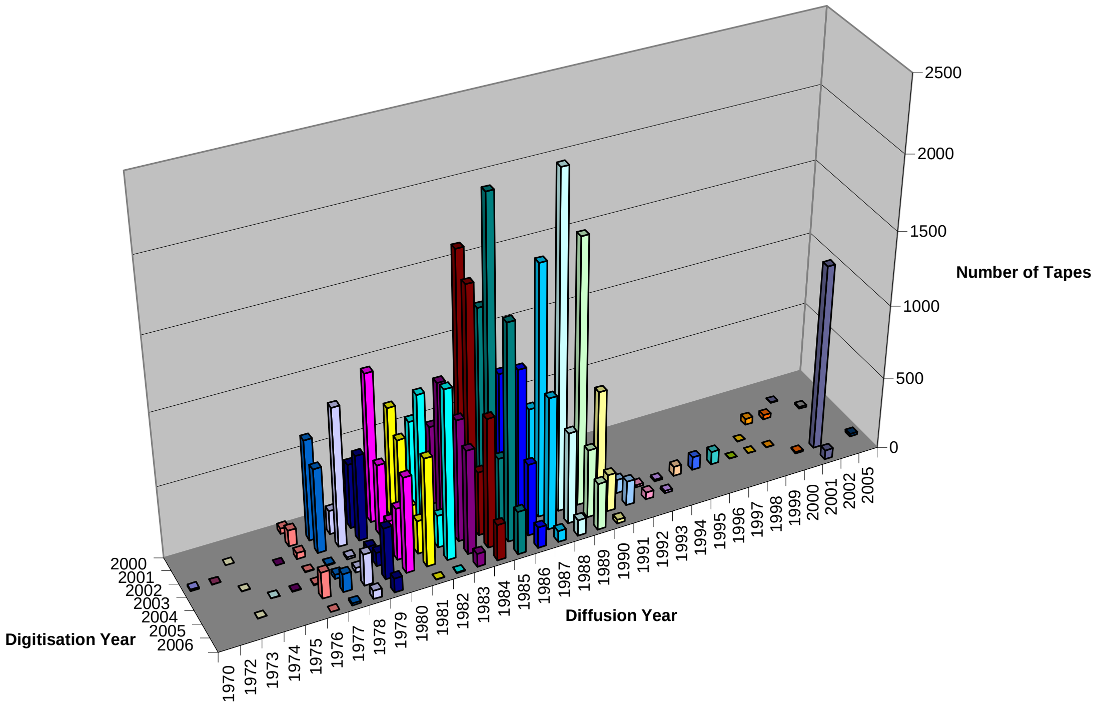

Figure 8 Population of tapes in the database

Diffusion year

It is immediately clear that coverage of diffusion years is not even. Tapes with diffusion year 1992 onwards are a very small fraction of the total tapes in the database and represent the 'tail end' of use of uMatic in the industry. Therefore, these tapes may not be representative of the general problems seen with uMatic. These tapes were excluded from our analysis. Likewise, very few tapes are in the database for diffusion year 1975 or earlier, so these too were excluded from our analysis. We also had some initial concerns that diffusion year 1976 should not be included in our analysis for since this was the first year that U-Matic was used to any significant degree by the broadcast industry, so there could be additional problems due to lack of user experience with this format at this time, the immaturity of the recording equipment available, or manufacturers still experimenting with tape formulations. Figure 9 shows that diffusion year = 1976 is not notably better or worse than other years when it comes to observation of head clogging in tapes. Admittedly, tapes from 1976 do show slightly more occurrences of head clogging than many subsequent years, but this may well be because the tapes are older than most others and hence have had more time to degrade in the archive. There is no strong evidence that 1976 is anomalous compared with other years in terms of playability problems and therefore we retained this year in our analysis.

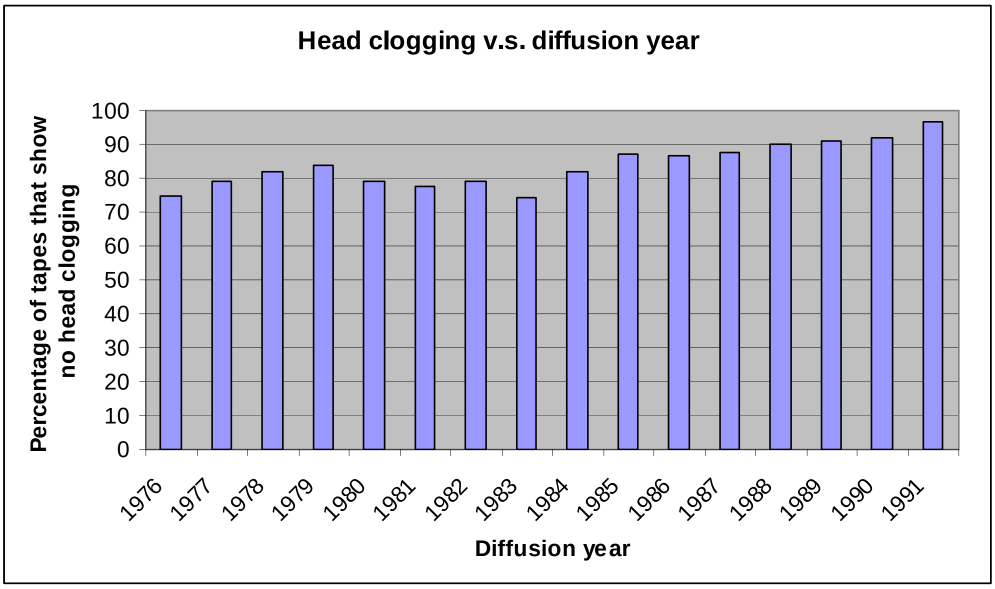

Figure 9 Occurrence of head clogging as a function of diffusion year

Digitisation year

Although not easy to see from Figure 8, when the digitisation year is 2000 only three different diffusion years are involved. This was also the first year that INA's service provider digitised INA's U-Matic tapes.

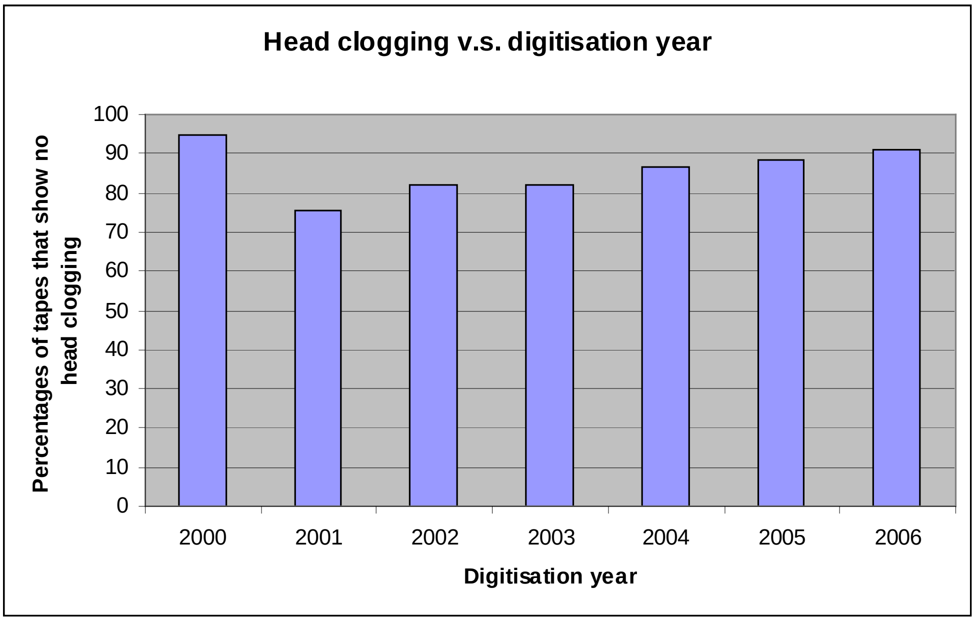

Figure 10 Head clogging as a function of digitisation year

Figure 10 shows that tapes that were digitised in the year 2000 appear to have fewer problems with head clogging than subsequent years. The reason for this is not known. For example, it could be that: (a) operators didn't bother to comment on the specific problems they found; (b) the terminology they used is different to other years and is not picked up by the automated processing of operator remarks; or (c) other more serious problems occurred with the tapes that meant head clogging wasn't measured. Whatever the reason, digitisation year = 2000 appears to be anomalous.

The number of tapes involved is relatively small (approx 200 tapes). Therefore, digitisation year = 2000 was excluded from our analysis.

The database was acquired for analysis in early 2006 before all digitisation work had been completed for that year. The database has entries for January and February in 2006, but not other months. The other digitisation years cover all months of the year. Therefore, in lieu of a more in-depth analysis to see if the number of playability problems varies with the time of year, we exclude 2006 from our analysis to be on the safe side.

Other database 'cleaning' operations and observations

Some tapes don't have a known digitisation or diffusion year, or the year that has been set is clearly wrong (e.g. diffusion dates that are in the future!). These tapes were excluded from our analysis.

Four of the brands (MAXELL, MX, PYRAL, QUANTEGY) had 100 tapes or less that were spread unevenly across several diffusion years, which we felt was not enough to draw conclusions without the risk that the results would be unreliable or biased for some unknown reason. Therefore, we have not included these brands in our analysis.

Figure 8 shows a small correlation between diffusion year and digitisation year. Tapes diffused more recently (i.e. the younger tapes) tend to be digitised more recently than the older tapes. This is understandable since it is natural for an archive to focus digitisation first on the older tapes in an archive since they will be perceived as being more likely to need immediate attention.

The question is what is the cause of this correlation?

Did INA's service provider get better at digitising tapes (e.g. improved techniques for tape cleaning or use of machines that don't clog so quickly) as time went on? This would mean that less head clogging is seen for tapes that have spent less time in the archive simply because they are younger tapes and were digitised later.

Or, have tapes that have spent more time in the archive degraded more than tapes that have spent less time in the archive since hydrolysis etc. has had longer to develop? If so, then since the older tapes tended to be digitised first, then this may explain why more head clogging is seen in the earlier digitisation years than the later ones.

Figure 11 shows how the percentage of tapes that show head clogging varies with the time the tapes have spent in the archive (digitisation year minus diffusion year).

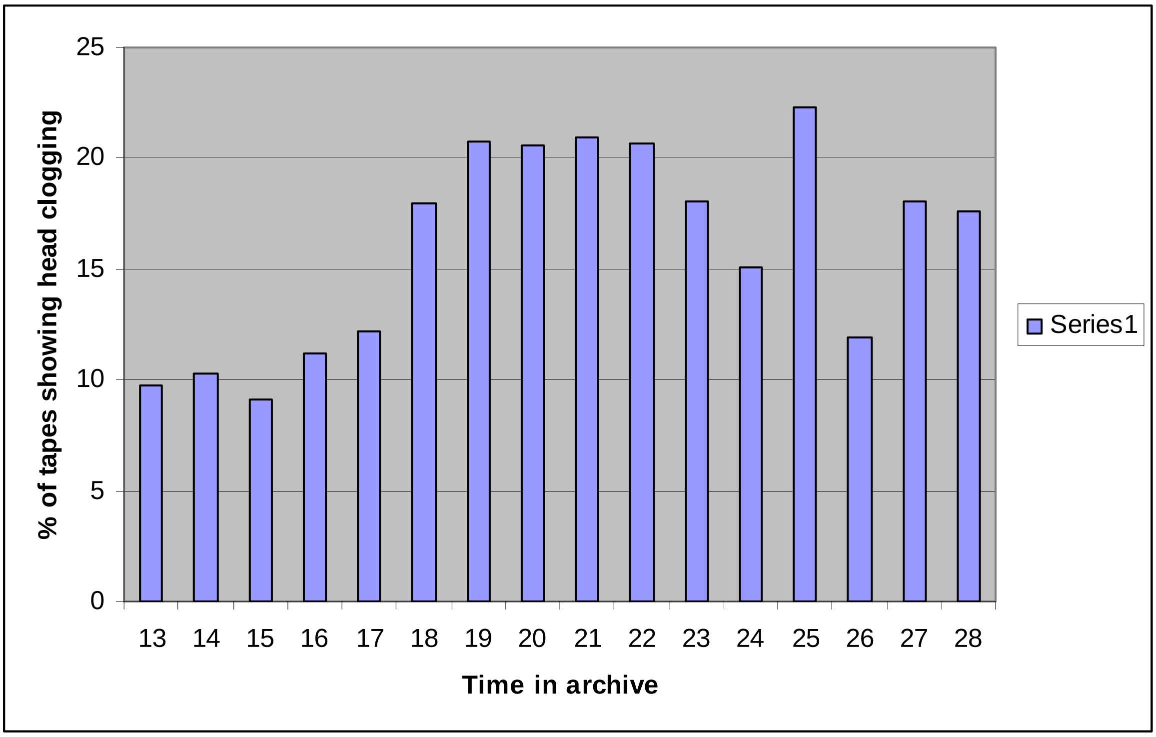

Figure 11 Head clogging as a function of time spent by tapes in the archive

At this point we observe that:

- There is a small correlation between time in the archive and the occurrence of head clogging.
- There is a small correlation between the age of the tape (diffusion year) and digitisation year.
- There is a small correlation between digitisation year and the level of head clogging.

Our approach to untangling the cause from effect, was to choose a brand (SONY) where the tapes for several consecutive diffusion years are dominated by a single tape formulation (e.g. 1982, 1983, 1984) and then by keeping the time in archive constant, we can look at whether there are any variations in head clogging between digitisation years. If there are then this will be a result of variations at the service provider rather than something arising from variations in the tape formulation or storage environment. This is shown in Figure 12 for the S8 group and in Figure 13 for the S6 group (more information on what S8 and S6 means can be found later in this section).

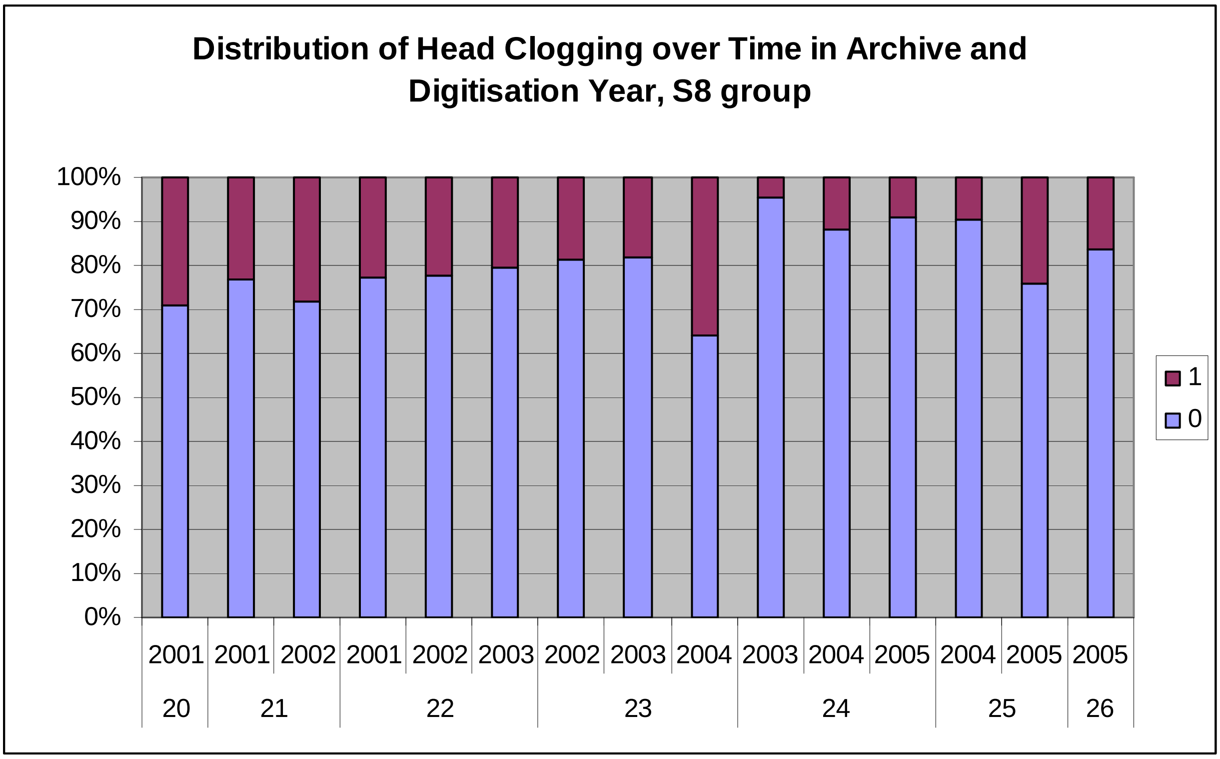

Figure 12 Distribution of Head Clogging over Time in Archive and Digitisation Years, S8 Group. On the x-axis, the upper year is the digitisation year and the lower year is the diffusion year. 0 = no head clogging observed, 1 = head clogging observed.

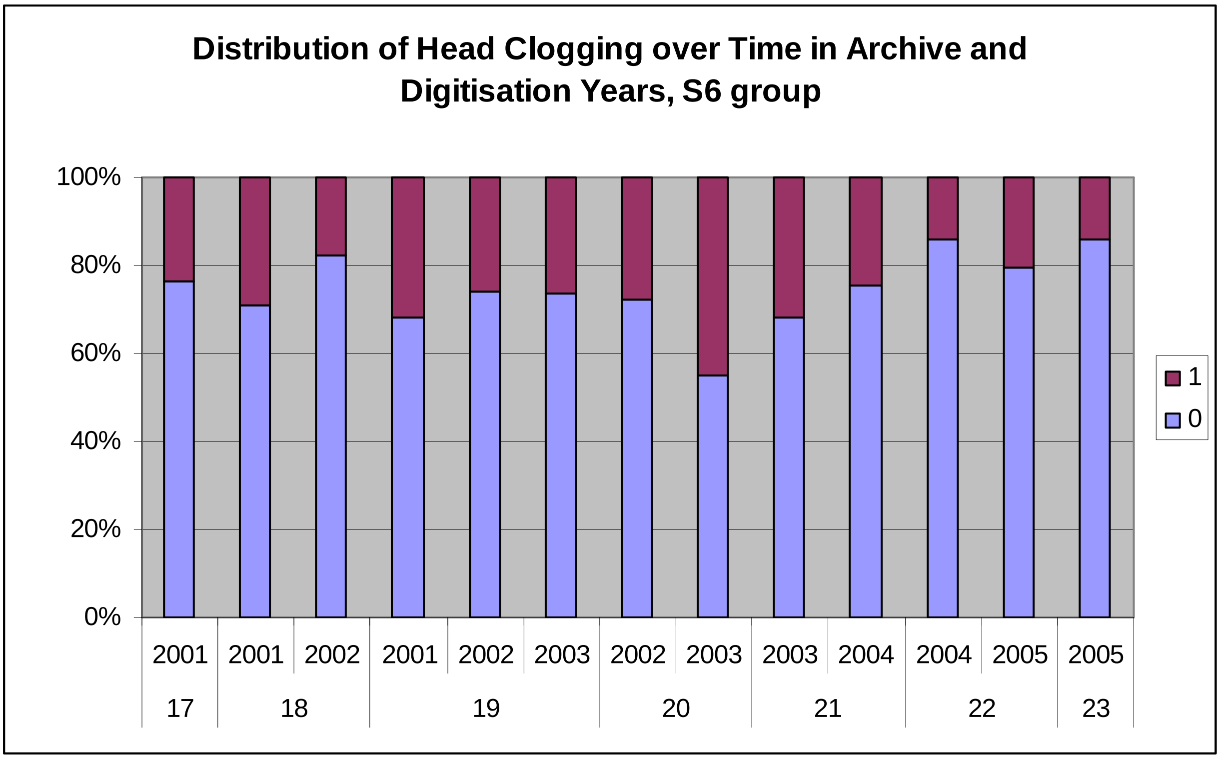

Figure 13 Distribution of Head Clogging over Time in Archive and Digitisation Years, S6 Group. . On the x-axis, the upper year is the digitisation year and the lower year is the diffusion year. 0 = no head clogging observed, 1 = head clogging observed.

For both S6 and S8 groups, for a fixed time in the archive, there is significant variation in the amount of head clogging that is seen for different digitisation years. There is no clear trend that for a specific group and fixed length of time that tapes have spent in the archive that head clogging is seen less frequently for the more recent digitisation years. This would suggest that the observed overall trend that tapes that have spent less time in the archive show fewer head clogging problems (see Figure 14, which is alternative way of presenting the data) is a result of environment effects of archive storage and not a result of improvements to the digitisation service over time.

However, the trends are small and there is significant noise in the data. Therefore, it must be stressed that this is a very tenuous conclusion and should be applied with extreme caution.

It is much safer not to draw conclusions on the cause of the slight trend, and hence instead we simply provide a table of recommendations to transfer operators to say what is likely to happen when they attempt a transfer of a tape of particular brand and diffusion year.

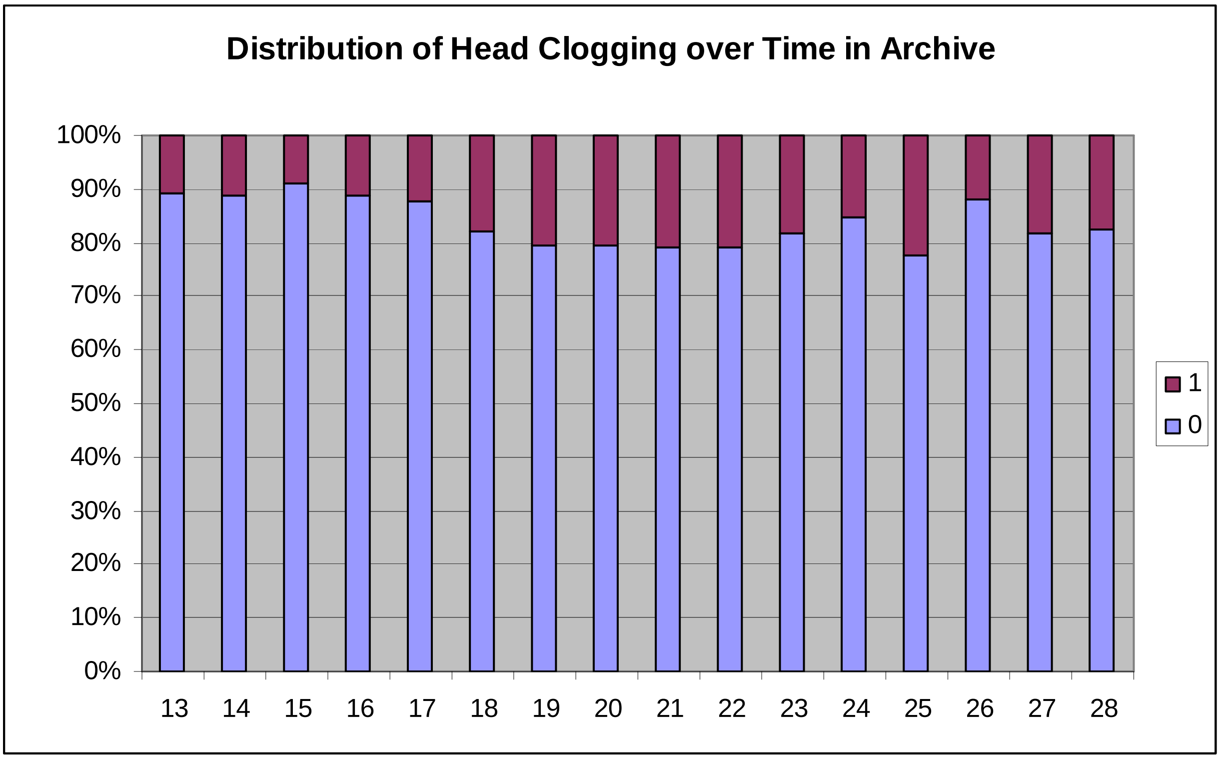

Figure 14 Distribution of Head Clogging over Time in Archive.
0 = no head clogging observed, 1 = head clogging observed.

The last step of dataset cleanup was to aggregate the defect classification levels for each type defect into just two classes: (a) no problem; (b) problematic. In most cases, a clear split could be made at "No problem" = defect level 0 and "One or more problems" = all tapes with defect level 1 and above. For head clogging, the vast majority of tapes were either defect level = 0 or defect level = 4. The cleanest split was defect level = 2 between the two classes (problems, no problems) since there was a clear dip in the number of tapes at this point.

Serial numbers, groups and chemical properties

Playability problems are dependant on tape formulation. Different manufacturers used different formulations at different times in tape production. The brand and age of a tape (tapes typically don't have a 'birth date' so even this can be hard to determine) is not sufficient to work out the specific chemical formulation used. The formulation can vary between batches in the same year. Worse still, there have been occasions where one manufacturer has re-branded stock from another manufacturer to ensure that they can keep up with demand. Therefore, not even the brand name on the tape label can be relied upon.

The only way to be sure of the tape formulation is to either do direct chemical tests on the tape or to use the serial number on the tape and compare this with serial numbers of tapes of known composition. Serial number structure varies between manufacturers, is not consistently applied by each manufacturer to their tapes, and often contains information like manufacturing date only in an encoded form (e.g. digits reversed and cycled). However, serial numbers from each manufacturer do appear to be clustered together into well defined groups and the assertion is that these groups correspond to the same tape formulation.

Therefore, to further investigate possible correlations between observed tape playability and the underlying chemical/mechanical/tribological causes, some 'samples' were made from the population of digitised tapes so that the serial number of the tape could be recorded and used as the basis of working out exactly what tape formulation had been used. The tape formulation was determined by either direct chemical analysis (done by CRCC), sometimes destructive, or by comparison with other tapes with similar serial number structure that had already undergone analysis. The result was the identification of 44 chemical groups as listed in Appendix E: Converting serial numbers to chemical groups.

Chemical properties and playability

The serial number was not recorded in the database of 60,000 tape transfers. To investigate relationships between tape playability and tape formulation, a subset of these tapes (1153) were selected and the serial number manually added to the database by inspection of the original U-Matic cassette. The tapes were selected with an emphasis on the ones that had been problematic during transfer, e.g. because digitisation had failed or head clogging had occurred.

Of these 1153 tapes, it was possible to unambiguously identify the chemical group of 818 of them (for 196 tapes the chemical group could not be completely resolved, e.g. it wasn't clear whether a tape was BSF1 or BSF2, and the others either could not be matched at all to one of the 44 chemical groups or had other information missing e.g. year of diffusion).

The tapes were predominantly AMPEX and SONY to allow detailed investigation of these two brands, but also included most of the other manufacturers.

The dataset for the 818 tapes with known chemical group underwent cleaning and processing steps similar to the larger database of 60,000 tapes. This resulted in each tape being classified as either 'problematic' or 'not problematic' according to whether it showed (a) head clogging, (b) need to be replayed to get a transfer, (c) or had a mixture of the two.

The distribution of chemical groups for a particular brand across diffusion years was investigated for each brand where there were enough tapes in the dataset (SONY) to create Group ID → Diffusion Year mappings.

Brand	SONY

	Group ID											
Diffusion Year	S1	S11	S12	S13	S14	S2	S5	S6	S7	S8	S9	Grand Total
1976									26	1		27
1977									19			19
1978									26			26
1979		1							2	12		15
1980	1				2		1		1	47		52
1981								6		60		66
1982								34		5		39
1983				1		1		76	1	3		82
1984				2			7	27				36
1985	1						34	7			3	45
1986	9			4			5	2			2	22
1987	2			1		6	1	3		1		14
1988			5	2		12	1	1				21
1989			34			5				1		40
1990			30			1						31
1991			22									22
Grand Total	13	1	91	10	2	25	49	156	75	130	5	557

Table 9 Distribution of SONY chemical groups across diffusion years

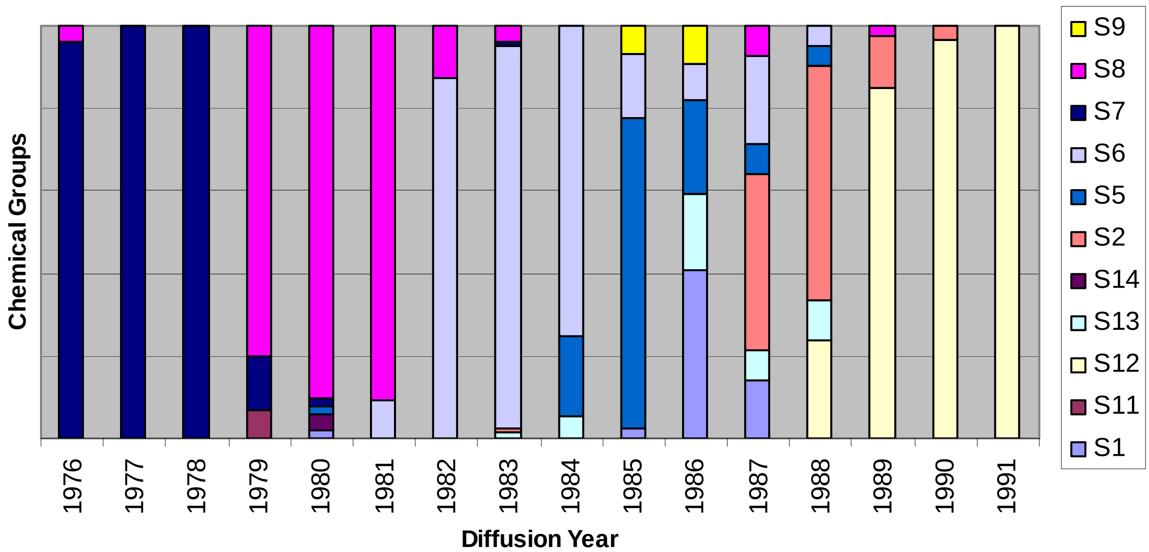

Figure 15 Distribution of SONY chemical groups across diffusion years

The relationship between chemical group and playability was analysed to determine which groups are relatively worse than others (Table 10). This is the basis of the playability problem rating table (Table 5) in Section 6.3. Since the selection criteria for the tapes in the subset are biased towards problematic tapes, the fraction of tapes that are problematic is higher than it is in the larger database and hence is not representative of the overall population. Therefore, Table 10 can only be used to calculate the relative playability of chemical groups, which results in the 1-9 playability problem rating in Table 5.

Using the mapping of chemical groups to diffusion years in Table 9 allowed comparison of the level of problems for the SONY groups in Table 10 to be compared with the level seen in the overall population (Table 1). This allows the level of playability problems seen in the subset to be rescaled to match the level in the overall population. There are some uncertainties in this process, e.g. due to overlaps between chemical groups and diffusion years, so detailed quantitative values were not possible. However, it was possible to give a ‘red’, ‘orange’ or ‘green’ classification to each chemical group (again see Table 5).

	Problematic (overall)		
Group ID	0	1	Grand Total
S1	18	2	20
S12	92	6	98
S13	10	0	10
S2	25	1	26
S5	46	10	56
S6	125	57	182
S7	52	24	76
S8	84	51	135
3M2	0	1	1
3M3	1	0	1
3M4	1	2	3
AGF2	7	4	11
AGF3	5	3	8
AGF4	7	10	17
AGF5	1	7	8
AGF7	2	0	2
APX1	12	2	14
APX2	61	21	82
BSF3	6	1	7
FJ1	49	2	51
FJ6	2	0	2
S11	1	0	1
S14	2	0	2
S9	4	1	5
Grand Total	613	205	818

Table 10 Number of tapes with playability problems for each group

Using data from CRCC on the occurrence of adipic acid in the tape formulation for some of the groups allowed investigation of the correlation between presence of adipic and tape playability. Of the 818 tapes where the chemical group is known, not all chemical groups have undergone lab analysis by CRCC so the presence of adipic acid or not was only known for 494 of these tapes (Table 11). A strong correlation exists between the presence of adipic acid and the occurrence of head clogging (Table 12).

	Adipic Acid		
Group ID	No	Yes	Grand Total
3M2	1		1
3M3	1		1
3M4	3		3
AGF4		17	17
AGF7	2		2
APX1		14	14
BSF3		7	7
FJ1	51		51
S6		182	182
S7		76	76
S8		135	135
S9	5		5
Grand Total	63	431	494

Table 11 Distribution of tapes across chemical groups according to presence of adipic acid.

	Problematic (head clogging)		
Adipic Acid	0	1	Grand Total
No	59	4	63
Yes	313	118	431
Grand Total	372	122	494

Table 12 Tape playability (head-clogging) for tapes in Table 11.
0=no head-clogging , 1= some head-clogging.

Adipic acid is a product of binder breakdown and has the potential to be a useful chemical marker of the binder breakdown process. The level of binder breakdown was measured by CRCC for one or two tapes from each chemical group. Lab analysis was used to look at the distribution of molecular weights of the binder components. The analysis done by CRCC reveals that the tape formulations most prone to chemical breakdown have adipic acid present.

As the binder breaks down, the average molecular weight becomes lower since long molecules in the binder are broken into smaller fragments. The weight average molecular weight for the binder components for several chemical groups which have adipic acid present (S6, S7, S8, AGF4, APX1) was compared to the playability of tapes from these groups. There is a clear correlation between the fraction of tapes with playability problems for a particular chemical group and the level of binder breakdown for that chemical group.

A straight line fit to the observed correlation for the 5 groups was then used to predict the level of playability problems that might arise for the other chemical groups that have undergone lab analysis by CRCC. The results are in Table 6 and Table 7 in Section 6.3.

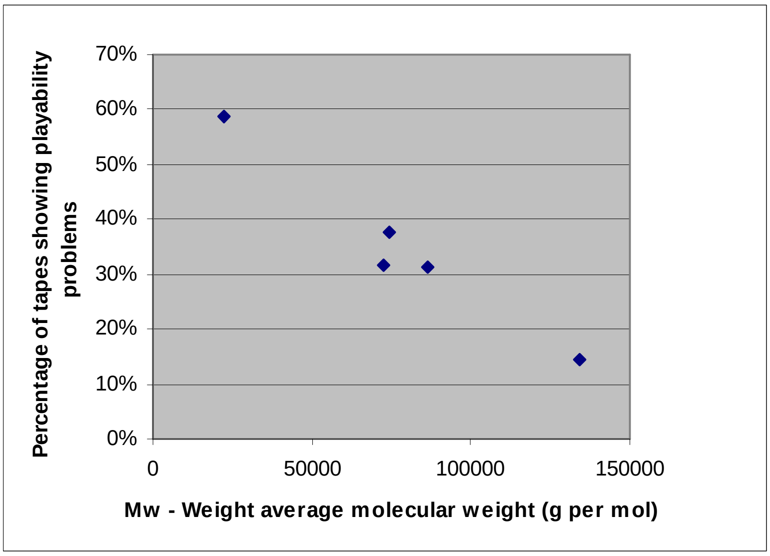

Figure 16 Correlation between average molecular weight of binder components with tape playability problems. The lower the average molecular weight (the more the binder has broken down) the larger the percentage of tapes with playability problems.

Playability Tables

The playability tables in this report were derived from the database after the cleaning and data pre-processing steps above had been applied.

The tables in Section 6.2 are derived from the large database and aim to reveal patterns/tends/hotspots based on brands and years.

The tables in Section 6.3 are based on the subset of the large database where the serial numbers are known and hence analysis could be done on the correlation between chemical groups and playability.

No one table in Section 6.2 or Section 6.3 covers all brands, years or chemical groups. This is because of the partial overlap between the large database of transfers, the subset where the serial numbers are recorded, and the analysis by CRCC.

Conclusions

It should be clear by now that a rigorous and complete analysis of tape playability problems with U-Matic tape (or any other type of tape for that matter) can only be done properly by using an extensive and very carefully structured database of tape transfer data. This is the only way to allow all the factors to be studied and separated so that the underlying causes of playability problems can be exposed. The data available to us in this study does not have the level of detail needed – for example, we don't know the year of manufacture for each tape only the diffusion year and we don't know the archive environment for the whole tape lifetime. The results of this report have to be used with this in mind. By making this statement, the intention is not to undermine the value of this report only to make it clear that the results should not be used blindly and without reference to how they were generated and what they really mean.