INTRODUCTION

Recent research in the Netherlands has focussed on the durability of the banknote on the note-coin boundary. In our case this is the NLG 10, about ECU 5. As you probably know, the note-coin boundary for the ECU-series will also be the ECU 5.

With respect to this issue I would like to discuss with you some aspects of 'durable banknote paper'.

In many countries, including the Netherlands, the same banknote paper is used for all denominations. The paper specifications have not been optimized for the use of the note.

Within the BPC the durability is most often measured by the life L of the note [1]:

\[
L = \frac{(\text{last year's notes in circulation}) + (\text{this year's notes in circ.})}{(\text{this year's new notes issued}) + (\text{this year's notes withdrawn})}
\]

The BPC/Statistic and handling committee have collected these life figures from the members. Unfortunately the latest figures are dated from 1991. According to (our complete) 1990-figures the longest average life is that of the notes from Greece (5.10 years), Austria (3.73 years) and Italy (3.32 years) [1].

The shortest average life in that year 1990 was found for the notes of England (0.84 years), Finland (0.97 years) and Ireland (1.01 year).

According to these figures the banknotes with a good reputation on durability, the US dollars have an average life of 1.91 years.
2 NUMBER OF CYCLES

I doubt whether everyone will agree with these conclusions. This can be explained because the life $L$ measures the total effect of five independent variables:

1. banknote design
2. banknote quality (paper quality + print quality)
3. sorting criteria
4. bank behaviour
5. public behaviour

This is the reason why in 1988 my colleague Mr Peter Koeze proposed another definition for the durability measurements of banknotes [2]. He suggested measuring the 'technical life', on the basis of the average number of loops or cycles a banknote can be used by the central bank. 

The journey that a note makes when it leaves the central bank and comes back is defined as one cycle. When a note leaves the central bank 4 times and comes back 4 times, the number of cycles $N = 4$. The central bank can use the note 4 times. A banknote will always make one cycle so that the durability cannot drop below 1. If a denomination tends to the asymptotical value of $N = 1$, this denomination ought to be replaced by coins in the near future.

Table 1 shows how this formula changes in 1994 the life $L$ of our Netherlands banknotes in the number of cycles $N$. What we see is that $N$ discriminates correctly for the weakest banknote, the NLG 10. If the common definition $L$ is used, the weakest banknote would be the NLG 50, which is not the reality.
The high unfit-rate of around 50% means that many NLG 10-notes are already over-used by the time they return to the central bank. We have the impression that the banks do not return the NLG 10-notes as quickly as the other denominations. Probably because the banks don't receive these notes from the shops and the public. Also of influence can be the relatively high transportation costs for low denominations and the fact that these notes are not used in ATMs. Finally of influence could be the recent 'money counting centrales'. In these centralised facilities the commercial banks match parts of their coin and banknote volumes from their different branche offices. The surplus they send back to the central bank.

<table>
<thead>
<tr>
<th>Denomination</th>
<th>Life L [Years]</th>
<th>Return frequency [1/Years]</th>
<th>Number of cycles N</th>
<th>Unfit [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NLG 10</td>
<td>1.5</td>
<td>1.3</td>
<td>2.0</td>
<td>48.0</td>
</tr>
<tr>
<td>NLG 25</td>
<td>1.4</td>
<td>4.0</td>
<td>5.6</td>
<td>17.5</td>
</tr>
<tr>
<td>NLG 50</td>
<td>1.1</td>
<td>5.6</td>
<td>6.2</td>
<td>15.1</td>
</tr>
<tr>
<td>NLG 100</td>
<td>2.7</td>
<td>3.4</td>
<td>9.2</td>
<td>13.3</td>
</tr>
<tr>
<td>NLG 250</td>
<td>7.4</td>
<td>0.8</td>
<td>5.9</td>
<td>10.4</td>
</tr>
<tr>
<td>NLG 1000</td>
<td>9.7</td>
<td>0.6</td>
<td>5.8</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Table 1

The life L, the number of cycles N and the unfit-rate of six denominations in the Netherlands (31 December 1994). 

\[ N = (\text{return frequency}) \times (\text{life L}) \]

Because all our denominations have the same paper quality we expect that the N-value is more-or-less the same for all denominations. According to Table 1 this is in our case \( N = 6 \). The NLG 100 has a higher N-value because we issued a new note in september 1993.

A further analyses of the figures in Table 1 shows that the N-value for the NLG 10-note is \( N = 2.0 \), which is very low. The conclusion might be that this note should be replaced by a coin, like the NLG 5 banknote was replaced by a coin in 1988.
3 PUBLIC OPINION

In 1994 we asked the public by means of a poll some questions about the NLG 10-note. The respondents clearly preferred a note (71%) instead of a coin (11%). No preference was the answer of 15% and 3% did not reply.

Although the public has a preference for a NLG 10-note, it is interesting to find that 75% answered that the NLG 10 is the dirtiest and most worn-out note.

The public receives the dirtiest notes at supermarkets (34%) and at the market (20%). Since the lowest value in ATMs is the NLG 25, people do not receive these notes, in general, from the bank. From the banks we did receive some complaints about the quality of the NLG 10-notes that they received from the central bank.

What can we do about this problem? We have asked ourselves how we can extend the life of the NLG 10-banknote. How can we double the number of cycles of a banknote?

4 EXTENDING LIFE

One of our first thoughts was of course the plastic Australian banknotes [3]. Mr Colditz reported a double life of the polymer notes compared to the cotton substrate. He also reported that the polymer notes stays cleaner. Why not introduce such notes?

Apart from our policy to buy banknotes in our own country we also have some technical arguments. The life of a note is, at least in our case, mostly threatened by dirt, as I have reported earlier, in 1992 [4]. If we make a rough qualification, we can say that the main reasons for declaring NLG 10-notes unfit are:
We have to keep in mind that most of the unfit NLG 10-notes are unfit for more than one reason.

One of our first conclusions is that, if dirt is the first reason for unfit declaration, a plastic substrate will not help much. The plastic will be covered by ink for about 80% of the surface. Dirt will stick to the ink in the same way on a plastic substrate as on a cotton paper. It is therefore more useful to look for better dirt-protection of the ink. The latest Australian polymer notes also have a thicker overcoating, to improve their feel and handling. Probably this coating will also improve the life of the note.

Apart from the Australian printing works there are, as far as we know, only two other banknote printers that varnish banknotes: Orell Füssli and Joh. Enschedé.

Dutch banknotes have been varnished since 1957. First with a polyamide film and since 1987 with a 'DAR Coating', based on the unique properties of cellulose. Using the DAR-varnish has increased the life of banknotes by almost 15% compared with not varnished notes [5].

Since my subject is durable banknote paper, I want to return to this subject.

5 DURABLE PAPER: GRAMMAGE

We have seen that circa 40% of the unfit NLG 10-notes are due to dog ears, holes and tears. Here better paper, or plastic substrate, could help.
But what are the specific paper specifications that influence the life of the note? We asked our paper mill VHP and their answer was:

1. grammage (mass, paper weight)
2. sizing
3. porosity
4. folding endurance (double foldings)
5. ash content
6. wet tensile strength
7. whiteness (colour)

And I would like to add:

8. banknote sizes

Most effective, according to VHP, is an increase of the grammage. Our paper has a grammage of 80 g/m² and could be increased to 90 g/m² (+12.5%). There is a direct relation between the grammage and tearing resistance; a 12.5% higher grammage leads to a circa 12.5% higher average tearing resistance.

Last year in Helsinki Mr Juan Teodoro reported also that the grammage of the paper was one of the two major parameters that influenced the results of artificial soiling tests: 92 g/m² is better than 83 g/m². The other influencing parameter according to Mr Teodoro is the smoothness level of the paper and he therefore suggests slightly calandered paper [6]. Our paper mill VHP agrees with this.

Looking at our 1994-overview of paper specifications we can see that many BPC-countries have a paper grammage of 90 g/m²: Austria, Germany, Turkey and Switzerland. With 70 g/m² for the new series France has the lowest grammage. The old French series had a grammage of 57 g/m².

An interesting question is now: do banknotes from countries with a high grammage have a longer life? It is not easy to answer this question, if we do not know N. Using the above mentioned 1990-data from the BPC/Statistics and banknote handling committee we read for the banknote at the note-coin boundary the following life L [1]:
Table 2
Overview of banknote paper grammage, lowest banknote denomination and life, according to BPC/Statistics and banknote handling committee, 1990.

As I have pointed out, the used definition of the life $L$ is not very adequate, the number of cycles $N$ would tell us more. On the other hand it is clear that, in the case of France, a low grammage indicates a short life.

6 DURABLE PAPER: OTHER SPECS

Apart from the dominant grammage-parameter, VHF mentioned six other paper specifications that can influence the life of a banknote.

Wrinkles obviously have an influence on the life of banknotes. Wrinkles can be measured by means of porosity, that measures the 'openness' of the paper after crumpling. The porosity of paper is mainly influenced by grammage and sizing. Sizing can prevent dirt penetration in the paper surface. Ideal would be a completely closed, flexible paper surface. This is not possible because a good penetration of the ink is necessary. The sizing is always an optimum between ink adhesion and dirt resistance.

Mr Juan Teodoro told us last year also that the sizing type is not a very helpful, important parameter in the artificial soiling test [5].
The folding endurance, measured by the double foldings, could be increased by the fibre length. On the other hand, will longer fibres lead to a more open paper. Here too, we have to choose an optimum.

Of course the ash content is of influence on the durability. Paper made of 100% cotton fibres has an ash content of < 0.5%. A higher ash content means that anorganic materials have been added, like dyes and titan oxyde. These materials could cause quicker wear and tear, because they can act like an abrasive when a banknote is folded and wrinkled. A security thread or for instance steel fibres will, for this reason, also decrease the life of banknote paper.

Banknote paper has in general a maximum of 5% ash content.

For a longer life, the ash content should be as low as possible. We use a specification of an ash content < 2%.

The wet tensile strength is also a parameter in the life of banknote paper. According to VHP this parameter cannot be optimized further. Our wet tensile strength is specified as > 25% of the dry tensile strength. This means a wet tensile strength of MD > 25 mN and CD > 12.5 mN. With this wet tensile strength our banknotes can be washed in the washing machine without falling apart.

The tensile strength can be increased by adding plastic fibres. In the early 70s we did some experiments with this. The reason at that time was that there were complaints from the public about the quality of the NLG 5, the note-coin boundary at that time. In 1974 we issued the NLG 5/Vondel 1 printed on Paressyn-paper, cotton paper with added plastic fibres. The Paressyn-notes were issued parallel with the same cotton notes. Although these Paressyn banknotes had greater tensile strength and greater tear resistance than the same notes made of 100% cotton, the experiments were not very successful. The plastic fibres were not completely embedded within the cotton fibres and attracted dirt, probably because of static electricity.
An important parameter is the colour of the paper. Dirt and spots on white paper are more easily seen than the same dirt and spots on coloured, for instance grey or brown, paper. A colour structure in the paper will also contribute, because spots on a non-homogeneous paper colour are less visible than on a homogeneous, even paper colour. And finally will a grey dirt shade be less visible on coloured paper than on white paper.

The last, but not least, parameter is the size of the banknotes. Banknotes that do not fit well in standard wallets suffer more in circulation than notes that do fit comfortably in a wallet. Since the height of the USA dollar is 65 mm (like several other important foreign notes), many (imported) wallets have a height of 80 mm. This means that our notes, that have a height of 76 mm often partly stick out of a wallet. This leads to more wear and tear at the long edges of the notes. Decreasing the height of the note to 65 - 70 mm would overcome this problem.

7 OTHER CONTRIBUTIONS TO DURABLE BANKNOTES

Apart from optimal paper specifications for durable banknotes, we will carry out experiments in the field of:
- anti-soiling design (for instance small clear watermark area, anti-soiling patterns)
- coating, varnishing (thicker layer, uv-cured types).

In our target to double the life of the NLG 10-notes, we think that these three measurement will contribute as follows:

- optimal paper specifications 15 %
- anti soiling design 50 %
- varnish 35 %
--- +
- Estimated increase of life 100 %
When the experiments on a laboratory scale are finished and we have selected one or more coating alternatives, we intend to issue these variants parallel to our standard DAR-varnish and not coated banknotes. With the help of our Number Reading System on the banknote sorting machines we can actually follow these variants in circulation and make hard conclusions about the real life of the variants. Measured in \( N \), the hypothesis is that \( N \) will increase from \( N = 2 \rightarrow N = 4 \).

We expect to finish our feasibility study this summer. Than we will start with the design of a new durable banknote at the note-coin boundary. Final decisions will be taken at the beginning of 1996.

8 CONCLUSIONS

1 Definition durability banknotes

There are several different quality aspects of banknote paper. The most discussed subjects are the security features and printability. Another subject is durability, the life of the paper. Usually the banknote paper is not optimized for durability.

Within the BPC-organization there are no hard figures on the life of banknotes. The best way to define the life of banknotes, using the data that central banks have, is the number of cycles \( N \) a banknote can be used. This life of banknotes \( N \) is the result of five independent parameters: banknote design, banknote quality, sorting criteria and circulation behaviour of banks and public.
2 Improvement paper durability

Grammage, synthetic fibres and paper colour are the three paper parameters that can be optimized for more durable paper for banknotes on the note-coin boundary.

Some degree of calendering can also help to prevent dirt attraction. Because of the average wallet height of 80 mm, the height of banknotes should be less than 70 mm. This avoids wear and tear along the long edges.

3 Improvement banknote durability

Apart from optimal paper specifications for banknotes at the note-coin boundary, a good coating and anti-soiling design can also effectively help to prolong the life of these notes.

9 REFERENCES

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