# Variations in Paper and in Print

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Abstract: In the task of achieving a more stable and repeatable print process, an insight in all possible sources of variation is necessary. Quality variations in paper and in printed sheets, causes for them and consequences of them are discussed in this paper.

E.g. in LWC paper, sinusoidal variations repeating every several meters can often be seen in coating amount and consecutively in gloss, in which variations can easily be even 10 %-units. This type of paper variation can consecutively be seen in the print quality in a similar way. In addition to paper related variations, the rotation of the printing cylinders cause variations in the print quality (e.g. density, gloss).

By reducing quality variations, savings can normally be seen e.g. in raw material and energy costs, downtime, and as faster start-ups.

## Background

In his keynote address at the 2001 TAGA Annual Technical Conference, Grant Miller, Vice President of Technology at RR Donnelley, stated, that the researchers and developers should be targeting their efforts towards achieving a "more repeatable and stable process". Factors greatly affecting the process stability are the raw material and the press itself, among others.

When the process stability is reviewed, it is of great importance to be aware of the variation in both raw materials and in the final product. This prevents drawing faulty conclusions about the process measurements, and the information can also be used in improving the sample taking and on-line control efficiency.

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In paper production as well as in traditional print production, the final product is affected by a large number of machine elements, such as rolls, cylinders, and in paper production also e.g. pumps, screens, felts (Cutshall, 1998). Because of wear, faulty production or faulty control of a machine element, the element can cause considerable variation in the final product. This can be seen in paper or in print as systematic variation, the repeat length of which matches with the rotational length of the element (Perento and Hilden, 1996). In this paper, this type of variation is referred to as machine direction or MD variation. A typical example of MD variation is variation of paper gloss at the repeat length, which matches the circumference of a roll in coating station.

Production width of paper and of printing machines has increased over the last decades, which has made controlling the uniformity of the final product more challenging also along the lateral or cross direction of the web. Normally there is an on-line control and/or measurement system, which aims to keep the profile of the web uniform. Both the control and the measurement are done at certain spacing, with control blocks of certain size. Normally, the profile of a paper machine web has a certain shape, with the edges differing from the middle part of the web. In addition to this, variation at the spacing of the control or the measurement elements can be seen. Also, MD variation can confuse the on-line scanners, which causes the CD control system to make false alterations in the profile (Fu and Nuyan, 2002). In this paper, this type of profile variation is referred to as cross direction or CD variation.

In addition to the MD and CD variations, there are small-scale variations in both paper and in print, often referred to as formation in paper, and mottling in print. In this paper, the emphasis is put on the larger scale MD and CD variations.

## Variation Measurement Equipment

For measuring the paper and print variations, a TAPIO® PMA-analyzer was used. With the PMA, several different properties of a moving sample can be measured simultaneously in laboratory. The different properties are aligned to compare them to one another. The PMA has several different sensors along a line, and the paper or print sample is passed through each of the sensors as a web. For sheet samples, several sheets are taped one after another to form a continuous web, which can be measured. With the analyzer's software, the tapes are removed from the analysis.

In this paper, the main interest lies in the following measurements:
- paper and print gloss,
- paper grammage,
- ash content
- printability index values (e.g. average light reflection, missing dots for gravure).

The measurements were done with all the sensors at 0.1 ... 12.8 mm spacing, depending on the type of sample. The measurement data can be digitally filtered with the software to examine variations of certain size. For instance, normally the longer-term trends are filtered out in order to examine formation level variation, or the very small-scale variation at formation level is filtered out when examining profile variation.

## Paper Variation

Examples of typical variations found in paper reels are shown below.

CD profile variation of a 90 g/m$^2$ coated printing paper produced at a 4.2 m wide machine is shown in Figure 1. The lower graph in figure 1 (X profile) shows the total ash content profile of the paper machine reel, and the upper graph (Y profile) shows the gloss profile of the bottom surface of the paper. The shown profiles are the average of 16 individual profiles, thus representing the steady-state profile, which is formed by the paper machine. The average profile is low-pass filtered in the software with a 20 mm digital filter to remove variation shorter than 20 mm.

There are several different types of variation in this profile. Firstly, there is a clear drop of ~1,5 g/m$^2$ in the level of ash content in the middle of the profile. This change in the ash content level can be seen as nearly 3 %-unit change in the gloss level of the bottom side.

Secondly, "swings" of slightly over 0.5 meter spacing can be seen especially between 2 ... 4 meters. These swings are at worst more than 1 g/m$^2$ in ash and 5 %-units in gloss.

Thirdly, there are smaller scale changes at the spacing of several centimeters in both ash content and gloss profiles. For instance, within the first 0.5 meters of the profile, the gloss values vary within more than 6 ... 7 %-units.

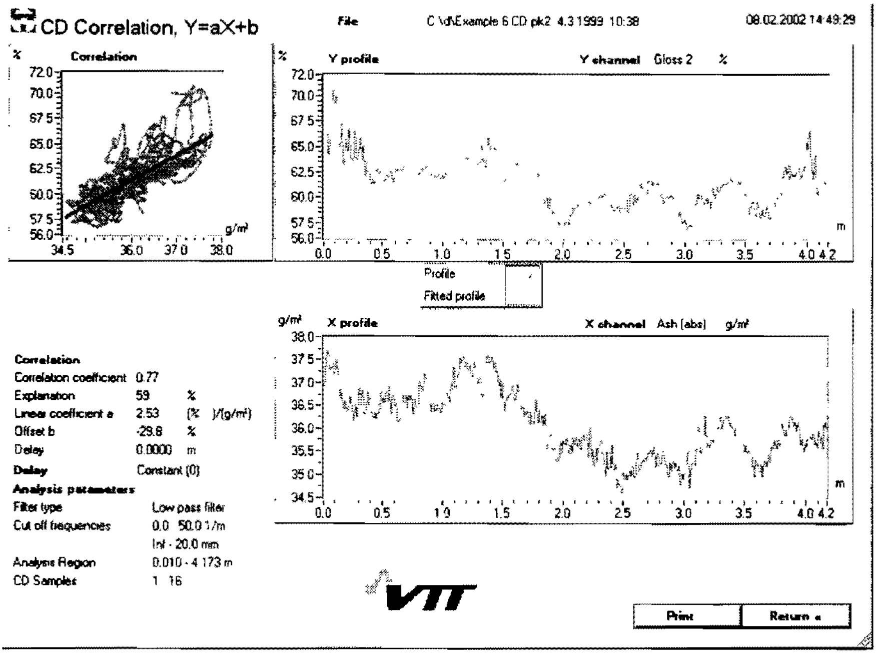


Figure 1. Correlation of total ash content and bottom side gloss CD profiles of a 90 g/m$^2$ coated paper.

The combined effect of all systematic and random variation in the profiles of figure 1 causes the gloss of the bottom side to vary between 57 … 70 %.

In the case presented in figure 1, depending on how the rolls are cut for the printing machine, there can be huge differences in the profile of an individual roll, or from one roll to another.

Figure 2 shows 100 meters of MD variation of an 85 g/m$^2$ coated offset paper. The lower graph in figure 2 (X profile) shows the MD total ash content profile of the paper reel, and the upper graph (Y profile) shows the MD gloss profile of the top surface of the paper. The MD profile is low-pass filtered in the software with a 60 mm digital filter to remove variation shorter than 60 mm.

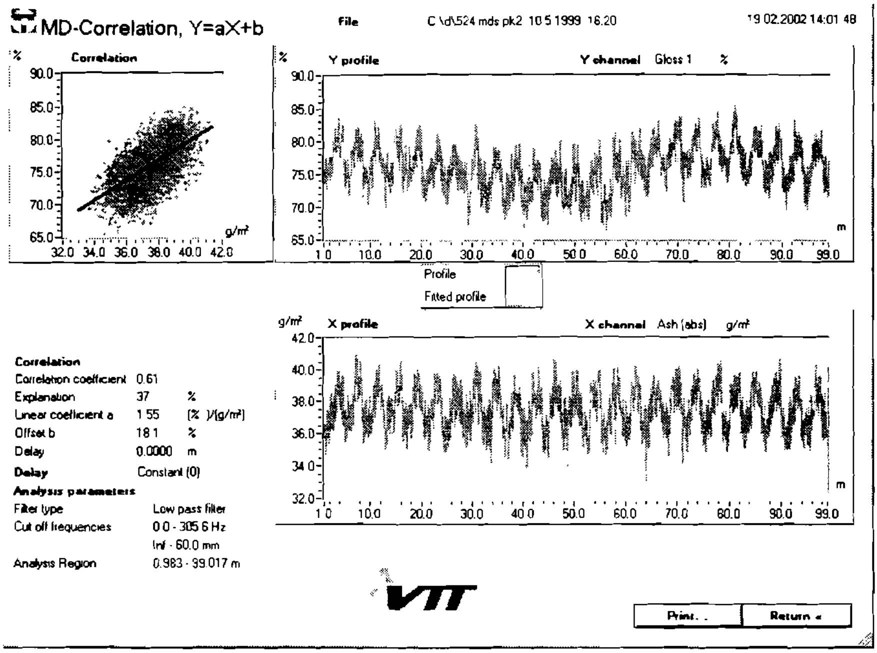


Figure 2. Correlation of total ash content and top side gloss MD profiles of an 85 g/m$^2$ coated offset paper.

There is clear periodical variation in total ash content, repeating every 3.9 meters. This same period can consecutively be seen in top side gloss. On average, the total ash content swings 3 … 4 g/m$^2$ within the 3.9 meter period. This causes the paper gloss to vary nearly 10 %-units at the same time.

In addition to the 3.9 meter variation, there is a longer term swing in the gloss, which reaches its lowest point at 40 … 60 meters from the beginning of the measurement. This causes a change of nearly 5 %-units in the level of paper gloss. The combined effect of these two variation types causes the paper gloss to vary between 68 … 85 % within the shown 100 meters.

Figure 3 shows 20 meters of MD variation in a base paper for 90 g/m$^2$ coated offset paper. The X profile in figure 3 shows the MD basis weight profile of the paper reel, and the Y profile shows the MD light reflectance profile of the paper. The MD profile is low-pass filtered in the software with a 60 mm digital filter.

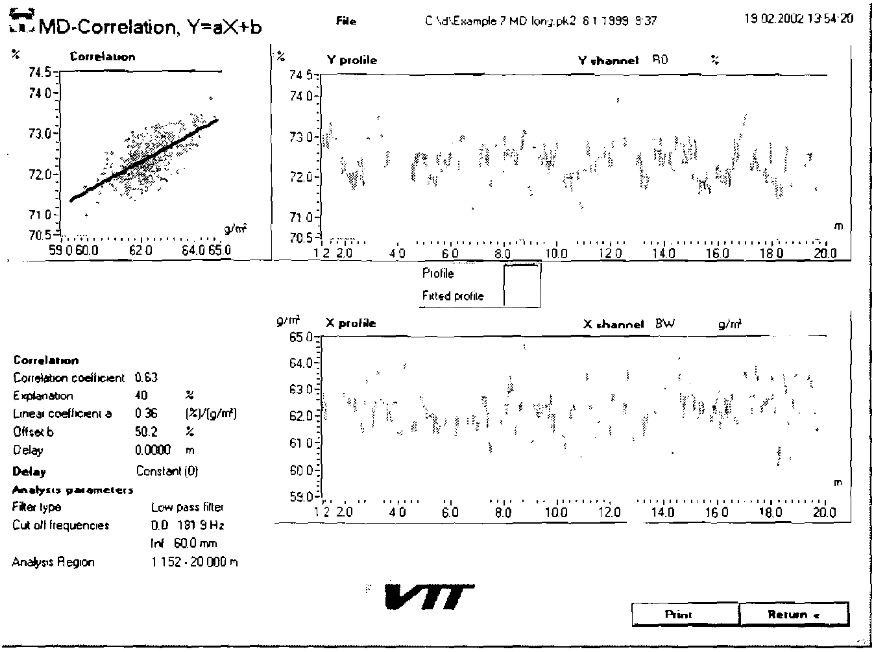


Figure 3. Correlation of MD variation in basis weight and in light reflectance (R0) of a base paper for 90 g/m$^2$ coated offset paper.

There are great repeating changes in the basis weight. At its worst, the basis weight changes nearly 5 g/m$^2$ within 20 cm. Some of this basis weight variation is consecutively seen in the light reflectance of the paper.

The light reflectance value, when measured from a single sheet, shows the remission, R0, of paper. Remission is partly affected by the brightness, and partly by the opacity of the paper.

The variation in basis weight was not seen as clearly in the final coated paper, since the overlaid coating covers some of the base paper variation. However, the variation in the fiber matrix is still present in the final paper.

## Print Variation

Examples of print variation in different types of printing machines are given in the following section. All these results were gathered from normal paper product development trials, in which the purpose of the trial was not to look for variation.

The variation along seven rotations of a test printing cylinder in a commercial gravure press is shown in figure 4. In this example, a continuous 15 % halftone strip was printed with one-color on 52 g/m$^2$ SC-paper. The printed sheets were taped one after another to recreate the continuous print strip, which was then measured to see the variations in the strip.

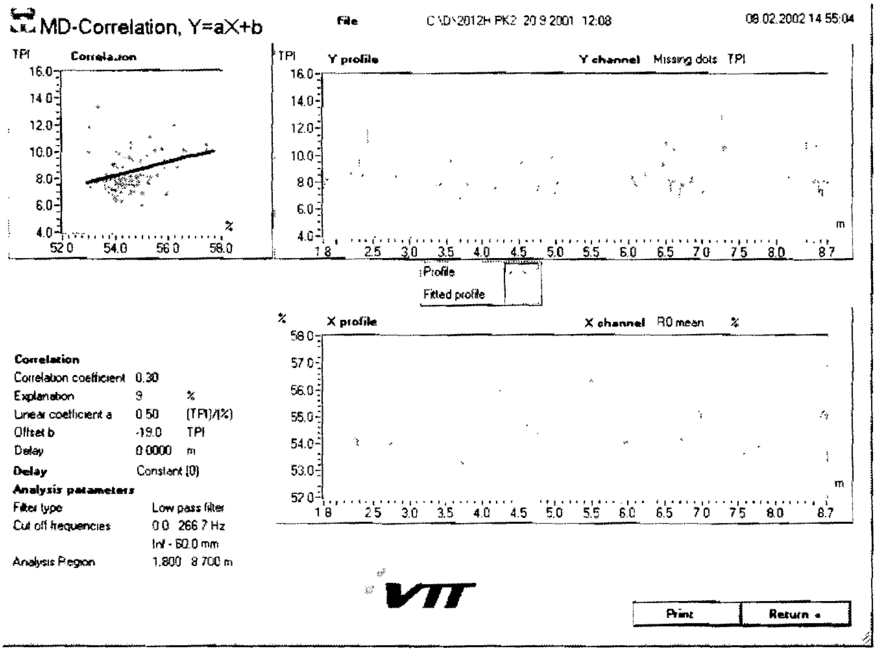


Figure 4. The correlation of variation in missing dots and in the average light reflection of a 15 % halftone area printed in gravure.

It is seen in the X profile of figure 4 that the average light reflection, which is relative to the print density, varies within one rotation of the cylinder as well as from one rotation to another. Even though missing dots is a more complex and random phenomenon, and is very much affected by the paper as well, it is seen that there is a tendency for higher number of missing dots in the areas, in which the print is of lighter tone. The average level of missing dots is fairly large, with 1 TPI-unit corresponding with approximately 10 missing dots/cm$^2$.

Variation of 100% black along seven cylinder rotations of the same printed paper as in figure 4 is shown in figure 5. In fulltone the tapes, which were used for attaching the sheet samples together, affect the readings greatly (two sheets form one full rotation of the printing cylinder). Disregarding the effect of the tapes, it is evident that also the fulltone print density varies along the cylinder rotation. The light reflectance values vary between 2.35 ... 2.7 % along the rotation of the print cylinder. This difference corresponds to variation between 1.40 … 1.47 in print density.

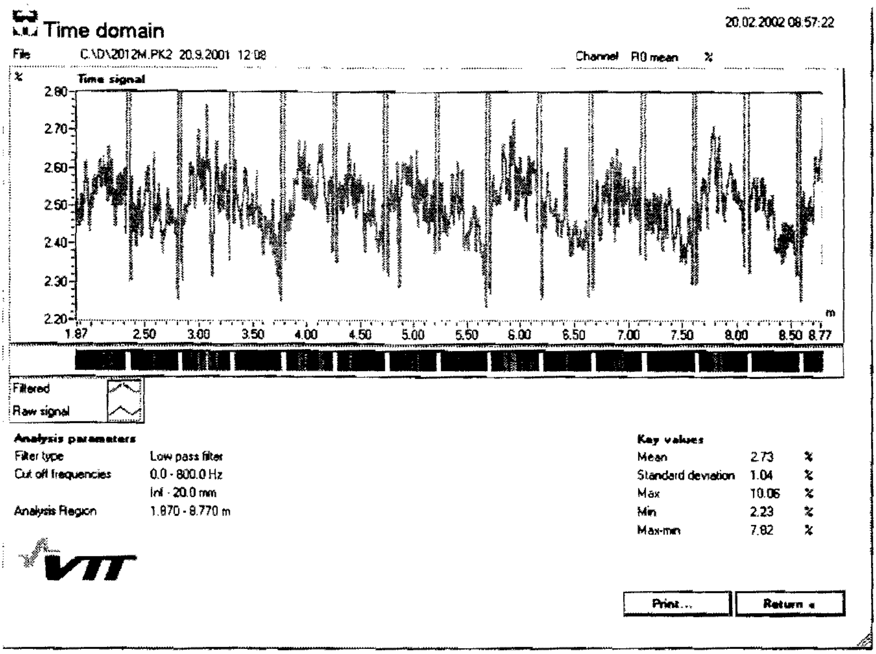


Figure 5. The variation in the average light reflection of 100 % solid black printed in gravure (the peaks, that exceed the y-scale, are caused by tapes).

Example of CD variation caused by a heatset offset printing machine is shown in figure 6. In this example, a 3-color 100 % solid test strip was measured. The strip was 46 cm along the cross direction of the web. The printing was done on 54 $g/m^2$ LWC paper.

The shown profiles are the average of 28 individual printed sheets, thus representing the steady-state profile, which is formed by the printing machine. However, it was noted that the shape of the light reflection profile was fairly similar in all of the sheets. The peak in the middle of the profile is caused by a fold in the printed sheet, and therefore is not to be noted as a flaw in printing.

There are swings in the light reflection along the width of the paper, repeating at approximately 8 cm spacing. The light reflection varies mostly between 1.05 … 1.3 %, which corresponds to approximately 1.7 … 1.8 in print density.

Close to the edges of the strip, the lighter print is causing a lower print gloss in these areas. In the right edge of the strip, the gloss changes from 68 % to 63.5 % within 3.2 cm.

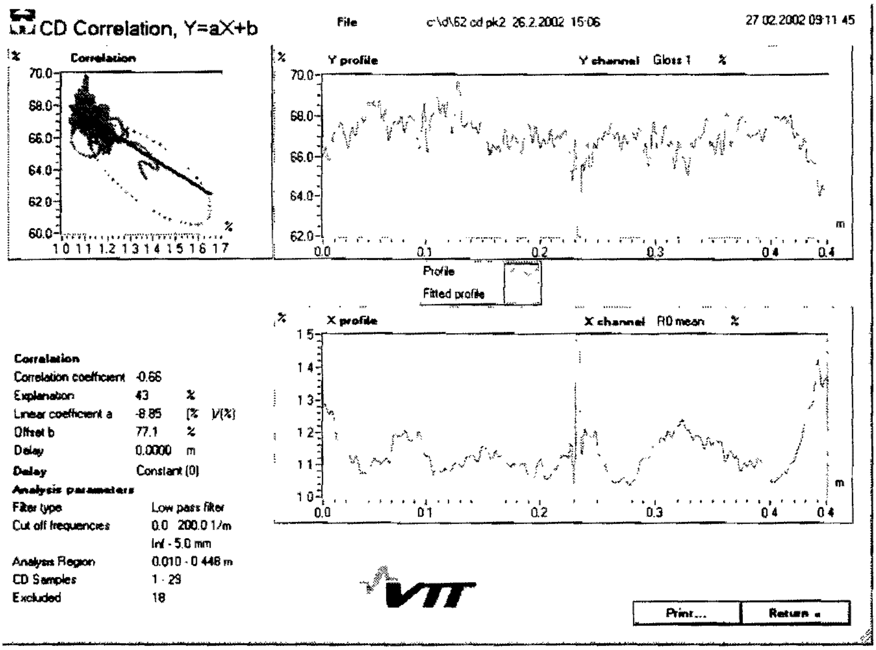


Figure 6. The CD correlation of variation in heatset print gloss and in light reflection of a 3-color 100 % solid (a fold in the sheet is seen in the middle).

Example of the effect of paper related variation in print variation is shown in figure 7. In this example, 60 g/m$^2$ LWC paper was printed in a test rotogravure printing machine described by Perento and Erho (1999). The printing machine prints from reel to reel, and 30 meters of a continuous 15 % halftone strip was measured. The measured signal is low-pass filtered in the software with a 60 mm digital filter to remove variation shorter than 60 mm.

In the paper, there was coating variation repeating at approximately 3 meter spacing, and this was consequently seen as variation in paper gloss. In the 15 % halftone print, the gloss variation is more than 10 %-units within the 3 meter sequence. This variation in paper causes the missing dots value to vary from 0.1 TPI to more than 1 TPI.

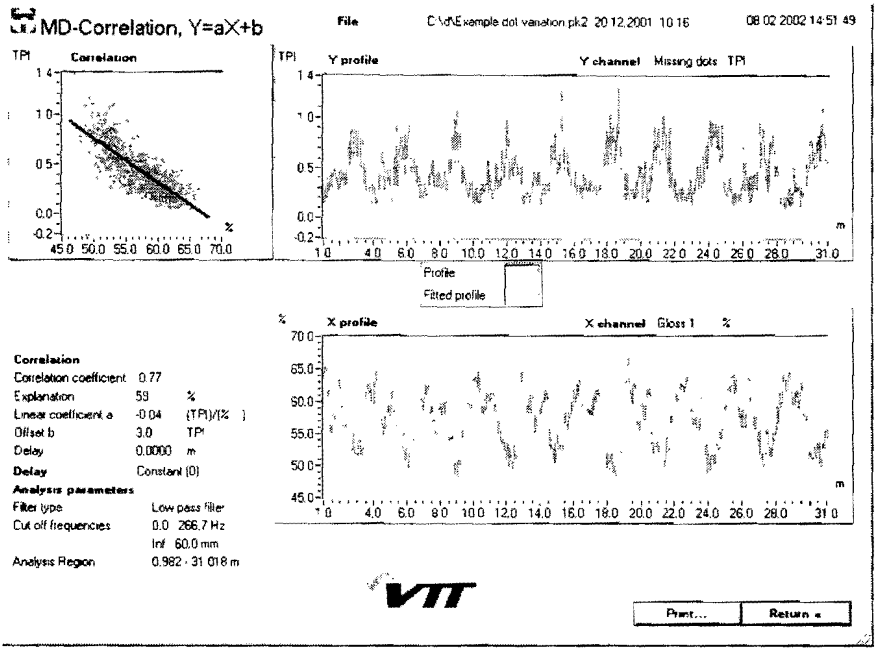


Figure 7. The correlation of variation in missing dots and in the gloss of a 15 % halftone area printed in a test gravure printing machine.

## Consequences of Paper and Print Variation

In addition to remarkable quality variations in the printed product, the variation in paper and in print can have various effects on the efficiency of the print process.

In start-ups, the paper or press related quality variations might prolong the start-up time, since it is actually impossible to achieve a constant level of operation. In any case, variation makes it more difficult and time-consuming to find the correct print conditions to achieve the correct print density and the correct print colors.

During a long print run, the variations may affect the raw material and energy costs. In order to achieve the minimum required print density on every sheet, for example, the amount of ink has to be high enough for even the poorest spot to pass the quality criteria. In other words, too much ink is applied at other spots on paper, which increases the ink consumption. In e.g. heatset printing, the energy required to dry every spot of the print needs to be adjusted according to the highest possible amount of ink. Therefore an excessive amount of energy is used in most parts of the printing. This, for its part, increases the energy costs related with drying.

If excess amount of drying is used, it might lead to other quality problems such as fiber rising, cracking or blistering, at worst. If this happens, the amount of misprinted paper increases.

Large basis weight, strength, or tension variations in a paper web increase the probability of web breaks in a web-fed printing process. For this reason, the downtime is likely to increase.

For paper product development trial purposes, the variation in the product could be turned into an advantage. As there is a lot of variation in paper, there are multiple of different paper grades tested at the same time. Therefore, the number of actual trial points in the paper production trial might be reduced.

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