A Method of Minimising Paper Requirements for Offset Printing

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The conducted study desired to increase the accuracy of estimating paper quantity requirements for printing. Changes in press construction and auxiliary equipment help reduce the total waste during production; however, typical estimation methods do not take these changes into account. By specifying the number of important job parameters and using a dimensional analysis approach, it was possible to devise a model of waste sheet quantity estimation better suited for current production practices. Using this model, it is possible to reduce the quantity of paper required for a particular print run as well as better predict the total waste sheet quantity. As a result, less paper may be ordered, stocked, and utilised in production. Using this model, a printing house may develop unique technological allowance standards for their particular substrates and products. The method of waste quantity prediction presented in this paper is also suitable for establishing a quality control system.

Keywords: Offset printing; Paper requirements; Paper waste; Dimensional analysis

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INTRODUCTION

In sheetfed offset printing, paper is always wasted in press setup and production errors (rejection *via* quality control procedures). In addition, the finishing processes require an additional allowance (this quantity is not affected by the printing process and is not covered in this paper). This means that during the printing process for a particular job, additional paper should be provided to account for "unsalable" production (Kipphan 2001). The additional paper provided is subsequently the technological allowance required to produce the final product. The additional quantity is calculated with respect to run length (*i.e.*, the required number of final products) and printing process characteristics (*e.g.*, type of press, number of colours). Formulae for such calculations are relatively simple and use statistical data from various sources, typically within one country (BPIF 2012; COBRPP 1986; Samarin 2002). Currently, there is widespread use of multi-colour presses, which use various automation systems (DeJidas and Destree 2005; Kipphan 2001) designed to shorten the makeready (press setup) time and reduce overall waste (Kipphan 2001). The industry-standard formulae have been found to be too pessimistic. For example, BPIF 2012 assumes that 500 waste sheets are required for each setup in four-colour printing. For that reason, paper quantity requirements have been calculated at a more drastic level than necessary. As the paper returns from production, sometimes it cannot be reused, and the surplus quantity drains both natural resources and company cash.

It must also be noted that waste paper (and any paper no longer suitable for printing after storage) must be processed, which consumes a varying amount of additional resources depending on the method selected (Hubbe 2007; 2014). Devising a method to limit the unnecessary allowance would make printing plants more sustainable. This particular study analyses the potential dependencies of paper waste on different factors, including printing process variables and the job data. The novel approach presented here may be useful as a starting point for creating company-specific models of estimating paper quantity for sheetfed offset printing process.

Estimating Paper Waste in Offset Printing

Basic estimation of paper waste in the sheetfed printing process is calculated using the following equation (Samarin 2002),

$$n_w = k(N_m + p_p \cdot n) \tag{1}$$

where n_w is the estimated number of waste (unsalable) sheets, k is the number of job colours (4 in the case of CMYK offset printing), n is the required quantity of printed sheets, N_m is the waste sheet quantity required for makeready, and p_p is the percentage of waste expected during the press run.

The values of N_m and p_p can differ depending upon the press type and configuration, paper type, quality requirements, and quantity range (Samarin 2002). In some cases, the outcome is multiplied by specific correction factors that depend on paper weight (grammage), sheet size, press equipment, *etc*. (COBRPP 1986). If a press run requires front and back printing, the method of predicting the waste quantity depends on the selected method of second side printing, number of plate sets required, or using a press equipped for single-pass double-sided printing (COBRPP 1986). Similarly, when the quantity required exceeds the durability of the offset plates used for printing, more makeready waste sheets must be provided (COBRPP 1986). The values for N_m and p_p are tabularised for convenience. To find an appropriate value, one must know which press will be used for printing the specified job, as well as what other conditions (such as the quality requirements) will apply.

The offset printing process is generally stable if set up properly (Kipphan 2001) and in a typical printing environment, one may assume that the press setup is the largest source of waste sheets during any print run. Notably, the predicted waste sheet quantity is directly proportional to the number of printed colours, meaning that setting up a four-colour (CMYK) job will generate significantly less waste than setting up a job including additional spot colours.

This correlation leads to overestimation of the waste quantity for many presses with five or more printing units, especially when such presses include automated functions such as plate changing, blanket washing, or pre-inking. These features not only shorten the makeready time (Kipphan 2001), but also reduce the number of waste sheets produced thanks to faster, more precise, and more repeatable performance of standard tasks. Because the cost of printing is the largest contributor to total production costs (DeJidas and Destree 2005), changes in this area can significantly affect the financial standing of the company.

EXPERIMENTAL

Theoretical Problem Analysis

A study undertaken in the Research and Development Centre for the Graphic Arts (COBRPP) was aimed at reviewing the current standards of computing the technological allowances for sheetfed offset printing in correlation to the actual numbers of waste sheets registered in commercial print runs. During this study, it was found that the estimation of waste sheets was generally too high and that the same quantity of waste was predicted for a wide variation of press runs. Therefore, a different approach for predicting the waste sheet quantity has been developed. The new method of predicting the waste sheet quantity can make waste estimates more realistic, inherently lowering the demand for natural resources. Such an approach was based on the notion that there are several common factors affecting the printing process, and it should be possible to find a relationship between appropriate similarity numbers using dimensional analysis.

A number of parameters describing a given print run were analysed. The parameters selected should be known at the moment of estimation and/or registered during the print run. The parameters taken into account are set forth in Table 1, where M is mass, L is length, and T is time.

Table 1. A List of Parameters for Estimating Waste Sheet Quantity

No.	Parameter	Symbol	Physical dimension
1	Number of copies (print run length)	n	Dimensionless
2	Number of pages in job	N_s	Dimensionless
3	Page size	S_s	L^2
5	Number of colours (separations) in job	k	Dimensionless
6	Print speed (number of sheets printed per time)	d	T^{-1}
7	Paper grammage	q	ML^{-2}
8	Sheet size	S	L^2
9	Ink tack	F_t	MT^{-2}
10	Ink consumption per area	q_s	ML^{-2}

With the exception of ink tack, all of the aforementioned parameters are regularly used in ordering and job description or costing. The ink tack, or a force required to split ink layers (*e.g.* between the inking rollers), is an important parameter of the offset printing process, influencing many of the effects observed in printing (Gujjari *et al*. 2006; Mangin and Silvy 1997; Mattila and Passoja 2006; Vähä-Nissi *et al*. 2010). Ink tack is measured using different methods (Hamerlinski and Pyr'yev 2013; ISO 12634 1996), and these methods establish many different units of ink tack. As a result, the ink tack values quoted in different papers are not directly comparable (Massolt 2003), but instead are consistent for any measurement method and may also be verified in-house. The physical dimension of ink tack results from its understanding as the ink-splitting work required per area unit (Shakhgeldyan and Zagarinskaya 1975).

Furthermore, it is important to note that all the parameters may have only positive values. Because ISO 12647-2 describes several types of paper used for printing, such as 5 or even 8 (ISO 12647-2 2004; 12647-2 2013), it was decided that the function should also be different for each paper type. This study concentrated on the three types of paper most widely used in sheetfed offset printing, *i.e.*, uncoated paper (equivalent to ISO type 4 in ISO 12647-2), coated paper (equivalent to ISO types 1 and 2), and cardboard. It also assumed that the required print quality is an average standard, with no exceptionally high or low deviations. Therefore the quality level was not considered a factor in the model. However, adding a scaling coefficient based on expected quality should be sufficient in practical cases.

Theoretical Formula Approach

Having established the set of characteristic parameters, dimensional analysis was used to formulate a relationship between the parameters and the number of waste sheets for a given print run, in the form of,

$$\delta = f(p_1, p_2, \dots, p_i) \tag{2}$$

where δ is the waste sheet coefficient (dimensionless) expressed as a ratio of waste sheet quantity to the number of copies printed, and p_i is a characteristic parameter of job or printing process.

Assuming that the function is a product of power monomials, it may be expressed as,

$$\delta = C_1 \cdot n^A \cdot N_s^B \cdot S_s^C \cdot S^D \cdot k^E \cdot d^F \cdot q^H \cdot F_t^I \cdot q_S^J \tag{3}$$

where C_1, A, B, ..., J are constants. Using dimensional analysis leads to the theoretical formula:

$$\delta = C_1 \cdot n^A \cdot N_s^B \cdot \left(\frac{S_s}{S}\right)^C \cdot k^E \cdot \left(\frac{q}{q_S}\right)^H \cdot \left(\frac{F_T}{S q_S d^2}\right)^I \tag{4}$$

Data obtained from actual press runs (using presses with 4, 5, and 6 units) in Polish printing houses were then used to calculate the values of the constants. The formula may be rewritten as

$$\ln \delta = \ln C_1 + A \ln n + B \ln N_s + C \ln\left(\frac{S_s}{S}\right) + E \ln k + H \ln\left(\frac{q}{q_s}\right) + I \ln \left(\frac{F_T}{S q_S d^2}\right)$$

Multidimensional linear regression analysis can be used to calculate the values of the constants used in the equation above.

RESULTS AND DISCUSSION

Based on 120 collected commercial job data printed with sheetfed offset presses, the multidimensional linear regression was applied for a subset of jobs printed on a particular type of paper, allowing to calculate the values of constant C_1 and exponents A, B, C, E, H, and I for each paper type separately. It was discovered with the help of *t*-statistics that some parameters specified in Table 1 are statistically irrelevant for certain paper types; in such case a new model, omitting the irrelevant parameter, was analyzed. The model was considered correct only when all *t*-statistics exceeded critical values and the coefficient of determination was higher than 0.8 for the analytical formula. As a result, the models for the different paper types are inherently different, as shown in Table 2. The regression analysis resulted in a quite simple model for cardboard printing.

Table 2. Formulae for Estimating Waste Sheet Quantity for Different Paper Types

Paper type	Waste sheet coefficient formula	R^2	Deviation RMS
Uncoated	$\delta = 4,63 \cdot n^{-0,74} \cdot \left(\frac{S_s}{S}\right)^{-0,56} \cdot k^{-0,47} \cdot \left(\frac{q}{q_S}\right)^{-0,54} \cdot \left(\frac{F_T}{Sq_Sd^2}\right)^{0,36}$	0.8250	19.9%
Coated	$\delta = 0,32 \cdot n^{-0,65} \cdot N_s^{0,07} \cdot k^{0,7} \cdot \left(\frac{q}{q_S}\right)^{0,19} \cdot \left(\frac{F_T}{Sq_Sd^2}\right)^{0,24}$	0.9555	10.8%
Cardboard	$\delta = 32,85 \cdot n^{-0,81} \cdot \left(\frac{S_s}{S}\right)^{-0,38}$	0.8444	26.0%

The estimated number of waste sheets may easily be derived from these equations by recognising that $n_w = \delta n$. Essentially, the relationship between n_w and δ entails that by adding 1 to the exponent of n in the equation from Table 2, one can obtain the formula for the waste sheet quantity.

The verification consisted of comparing the actual waste sheet quantity with the theoretical quantity computed using the appropriate formula for each case used in the linear regression model. The Root Mean Square (RMS) deviation of theoretical values from the actual figure is shown in Table 2 as a percentage of actual values.

Interestingly enough, regarding cardboard, the number of colours printed has no influence on the estimated quantity of waste sheets. For all types of paper, the exponents for quantity and number of colours vary drastically, suggesting that the number of waste sheets is in fact not directly proportional to the number of colours printed. The R^2 values indicate that these models are efficient enough to be used in industrial practice, a claim further supported by the values of the deviation of the root mean square from the actual print run data. The highest accuracy for the model was observed when studying coated paper.

Finally, to verify the model, the formulae have been used to calculate the expected waste quantity for some print runs not used in the linear regression. In comparison to standard waste sheet estimating methods (COBRPP 1986; Samarin 2002), it was found that the new model minimises the quantity of paper required for printing. In most of the comparative cases (taken from the number of experiments not used for linear regression analysis) depicted in Fig. 1, the quantity of waste sheets estimated using the new model was the most accurate in predicting the actual waste sheet quantity registered during the print run. Additionally, the waste sheet figures produced by the new model were consistently lower than any of the other models tested. The new model also properly predicted an unusually high quantity of waste associated with printing on cardboard (case 6), whereas the other methods produced results much lower than the actual value (Fig. 1). In case 5, the estimated waste sheet quantity was higher than not only the actual value, but also the quantity estimated by other methods (Fig. 1). However, that particular case used UV varnishing, which could have affected the credibility of the averaging of the ink consumption and ink tack required for calculation, according to the developed model. Nevertheless the model is suitably close to the experimental data even it such a case.

Table 3. A List of Parameters for Test Print Runs

Test Print No.	Number of copies (print run length)	Number of colours (separations) in job	Print speed (number of sheets printed per time) [sheets/hr]	Paper grammage [g/sqm]	Sheet Size [mm x mm]
1	375	4	10,000	100	630 x 880
2	2500	4	8,000	130	350 x 500
3	1000	5	11,500	250	610 x 860
4	3000	4	8,000	130	500 x 700
5	550	1	7,000	80	610 x 430
6	2650	3	7,500	350	700 x 1000
7	2020	4	8,000	130	305 x 430
8	1600	5	11,000	200	630 x 880

The result of the comparison is shown in Fig. 1. This radar plot shows an actual quantity of waste sheets compared with three methods of estimating the waste quantity, “Theoretical” corresponding to the model discussed in this paper. It may be observed that it matches the actual figures better than the other two models.

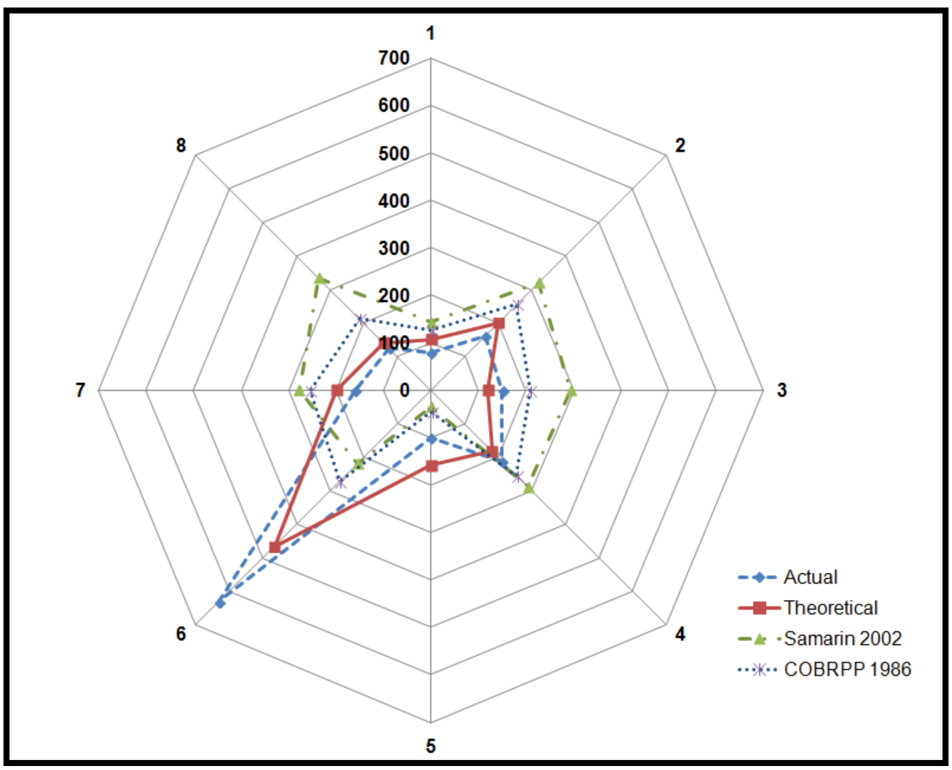

Fig. 1. A comparison of different standards of waste sheet calculations *vs*. actual values from a sample of eight print runs in Poland

CONCLUSIONS

1. Using the discussed method of estimating waste sheet quantity for a given sheetfed offset print run, it is possible to limit the quantity of paper for production, saving capital outlay and reducing environmental impact. The method is particularly suited for multi-colour sheetfed offset printing and is feasible for both short and long print runs. Its practical application will depend on the number of available data for analysis, and on the verification of basic assumptions regarding quality, work practices etc.
2. The presented model is adaptable to the particular conditions of any printing house, by allowing an analysis of data gathered from the production runs for more precise estimation of the waste quantity in subsequent jobs. The results may be periodically reviewed to reflect changes in equipment, quality requirements, operators' experience, *etc.* Most spreadsheets used for reporting and analysing various aspects of production management are capable of performing the calculations required for this model.
3. The method is also suitable as an input for statistical quality control (SQC) and the various indicators used in "lean" production management systems.

REFERENCES CITED

BPIF Standard Document (2012). *Allowances for Overs/Unders and Wastage*, British Printing Industries Federation, Coventry, UK.

COBRPP (1986). "Materialy Pomocnicze do Opracowania/Weryfikacji Zakładowych Normatywow Zuzycia i Norm Ubytkow Oraz Systemu Rozliczen Materialow Poligraficznych (Supporting Information for Setting Up and Verifying Technical Allowances, Waste Sheets and Substrate Accounting System)," Branzowy Osrodek Normalizacji, Branzowy Osrodek Informacji Naukowej, Technicznej i Ekonomicznej, Warsaw, Poland.

DeJidas, L.P., and Destree, T. (2005). *Sheetfed Offset Press Operating*, GATF Press, Sewickley, PA.

Gujjari, C., Batchelor, W., Sudarno, A., and Banham, P. (2006). "Estimation of ink tack in offset printing and its relationship to linting in offset printing," *Proceedings of TAPPI International Printing and Graphic Arts Conference*.

Hamerlinski, J., and Pyr'yev, Y. (2013). "Modelling of ink tack property in offset printing," *Acta Poligraphica* 1(1), 31-40.

Hubbe, M.A. (2007). "Incinerate, recycle, or reuse?," *BioResources* 2(1), 1-2.

Hubbe, M.A. (2014). "Recycling paper recycling," *BioResources* 9(2), 1828-1829.

ISO 12634 (1996). "Graphic technology - Determination of tack of paste inks and vehicles by a rotary tackmeter," *International Standards Organization*, Geneva, Switzerland.

ISO 12647-2 (2004). "Graphic technology - Process control for the production of halftone colour separations, proof and production prints - Part 2: Offset lithographic process," *International Standards Organization*, Geneva, Switzerland.

ISO 12647-2 (2013). "Graphic technology - Process control for the production of halftone colour separations, proof and production prints - Part 2: Offset lithographic process," *International Standards Organization*, Geneva, Switzerland.

Kipphan, H. (2001). *Handbook of Print Media*, Springer Verlag, Heidelberg/Berlin.

Mangin, P.J., and Silvy, J. (1997). "Fundamental studies of linting: Understanding ink-press-paper interactions non-linearity," *TAGA Proceedings, Technical Association of the Graphic Arts*, p. 884.

Massolt, P. (2003). *Keep Your Tack on Track*, VIP Publications, Testprint, Cherry Hill, NJ.

Mattila, U., and Passoja, S. (2006). "Factors controlling adhesion and ink tack in HSWO (Heatset web offset)," *Proceedings of International TAPPI Printing and Graphic Arts Conference*.

Samarin, Y. (2002). *Normativy Razkhodovanya Osnovnykh Poligraficheskikh Materialov (Standards for Production Usage of Graphic Arts Materials)*, Moscow State Print University, Moscow.

Shakhgeldyan, B. N., and Zagarinskaya, L. A. (1975). *Poligraficheskiye Materyaly (Graphic Arts Materials)*, Izdatelstvo Kniga, Moscow.

Vähä-Nissi, M., Kela, L., Kulachenko, A., Puukko, P., and Kariniemi, M. (2010). "Effect of printing parameters on delamination of board in sheet fed offset printing," *Appita Journal* 63(4), 315-322.

Article submitted: April 8, 2014; Peer review completed: May 7, 2014; Revised version received: July 1, 2014; Accepted: July 2, 2014; Published: July 14, 2014.