PREDICTING SEQUENCE DEPENDENT SET-UP TIMES FOR MULTI-STATION MACHINES (A CASE STUDY)

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Abstract

The set-up time for jobs on some multi-station machines, such as manually configured colour printers, are sequence dependent. Many techniques exist for finding a sequence in which to process the jobs to reduce total set-up time significantly. They all require an estimate of the set-up time for each job given the set-up of the previous job. In practice predicting set-up times for scheduling purposes may become prohibitively time consuming. In this article a practical technique is presented that estimates the set-up time for a job on a multi-station machine, such as a manually configured printer. An application in a corrugated cardboard box factory, where the technique is in use as part of a computerised scheduling system, is discussed.

Opsomming

Die opsteltyd vir take op sommige veelstasie masjiene, soos handgekonfigureerde kleurdrukkers, is volgorde afhanklik. Vele tegnieke bestaan om die volgorde te bepaal waarin take geprosesseer moet word om opsteltyd beduidend te verminder. Al die tegnieke vereis die opsteltyd van die volgende taak, gegewe die opsteltyd van die voorgaande taak. In die praktyk mag raming van opsteltye vir skeduleringsdoeleindes onhanteerbaar lank neem. In hierdie artikel word 'n praktiese tegniek beskryf wat die opsteltyd beraam vir vir 'n taak op 'n veelstasie masjien, soos 'n handgekonfigureerde drukpers. 'n Toepassing in 'n riffelkartondoos fabriek, waar die tegniek toegepas word as deel van 'n gerekenariseerde skeduleringsisteem, word bespreek.

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1. INTRODUCTION

With multi-station machines, such as manually configured colour printers, the amount of work required for setting up a printer for a specific job depends upon the configuration of the printer for the previous job. The operator decides, for example, which colour to load on which station for a new job, based on the set-up of the previous job. For scheduling purposes it is necessary to predict the set-up time, and therefore the choice of the operator. Furthermore, the number of combinations of colours and stations preclude exact calculation of set-up time for each specific job sequence.

The total time required for setting-up for a group of jobs can differ significantly from one sequence to another. Choosing the best sequence for a group of jobs can increase the available production time greatly. Many techniques exist for creating a sequence. Literature on scheduling, however, addresses the complexities of scheduling, disregarding practicalities such as calculation of time dependent set-up times, that may be so time consuming and unmanagable, that implementation of the techniques are impossible. The authors are convinced that the technique for predicting set-up times presented in this paper, that they developed and successfully implemented, is completely new. It does not make sense to include an exhaustive list of literature surveyed, but the first and last references, alphabetically, are Ashford [1], and Worral [3]. The technique was developed as part of a computerised scheduling system developed for a cardboard box manufacturing company [2]. The following discussion addresses this specific application, since it provides a good example of the generic class of applications, namely, predicting sequence dependent set-up times for multi-station machines.

2. SET-UP OPERATIONS ON MANUALLY CONFIGURED CARDBOARD PRINTERS

Cardboard printers consist of several printing stations. Each printing station is responsible for printing one colour and one image only. Overlaying colours and images produces a multicoloured print. A single colour print requires only one printing station. A two-colour print requires two printing stations, and so on.

When a new job is loaded on a printer, the printing stations (among other less time-consuming operations) need to be re-configured for the new job. Normally, this means rinsing the current colour of ink out of the printing station and removing the stereo. The stereo is responsible for printing the actual image. Then the new colour of ink and stereo is loaded. The most time-consuming part of the operation is the process of changing the ink. Reducing the number of ink changes required from one job to the next saves much time.

This is done by matching the colours of inks used on printing stations for an old and a new job, if the two jobs use one or more identical colours. In other words, if a printing station has black ink loaded in it (which was used for the old job), and a new job also uses black ink, then the operator will try to keep that ink in that printing station and use it for the new job as well. This will save him having to rinse the ink out of that printing station and load a new colour.

This process of matching colours is not always possible, because a certain sequence of printing is required for multicoloured prints. A multicoloured print's different coloured images are printed over each other in a fixed order. The lighter coloured images must be printed first, followed by the darker colours. This prevents darker colours from "shining through" lighter colours that would otherwise be printed over them (there is always a bit of overlap between colours). For a specific job one can specify the order in which the colours that make up the image should be printed.

For a printer with three printing stations the following situation can occur. Imagine a printer operator is printing a two-colour job consisting of yellow and dark blue colours. The sequence for printing the colours is yellow first, then dark blue. The operator decides to use printing station one for the yellow and printing station two for the dark blue ink. A new two-colour job arrives, consisting of dark blue and black. The sequence for printing the colours specified is first dark blue, then black. When loading the new job the operator has three options: he can load dark blue on printing station one and black on printing station two, or he can load dark blue on printing station one and black on printing station three, or lastly, he can load dark blue on printing station two and black on printing station three. Clearly the last option requires the least work, because an ink change in printing station two is not required. This is the option a printer operator is very likely to choose in real life.

Any system that tries to predict the set-up time for a new job must predict what option an operator is likely to take when loading a new job. This is because the option the operator takes dictates which set-up operations must be done for the new job. The technique presented in this article predicts what option an operator is likely to take when loading a new job. This dictates the resulting operations that must be completed to re-configure the printer and therefore how long the set-up operation will take to complete.

3. THE TECHNIQUE FOR ESTIMATING THE SET-UP TIME FOR A JOB ON A MANUALLY CONFIGURED PRINTER

The technique requires information about the printing sequence for the colours of each job, to enable it to estimate the required set-up time for a new job. A simple two-colour print job on a three-station printer is used to explain the technique. The more complicated real-life situation is discussed in paragraph 4.

The following example of a printer with three printing stations will help to explain the technique. Assume that this printer requires no set-up operations other than ink changes when a new job is loaded. Assume too that this printer has just completed a two-colour job, consisting of colours W and Y. W prints before Y because it is a lighter colour. On the three-colour printer colours W and Y could have been loaded in the printing stations in three possible ways: W on printing station one and Y on printing station two, W on printing station two and Y on printing station three, or W on printing station one and Y on printing station three. A new two-colour job arrives that shares one colour with the old job. The new job can also be loaded in three different ways. It should be clear that many possible combinations exist for ways in which the old job was loaded and ways in which the new job can be loaded. By investigating each case separately one can see what the possibility of matching colours is for this example as a whole.

If the first colour printed for both jobs is the same, then the situations as described by table 1 are possible. It is clear from this table that an ink change saving will be possible for this case, irrespective of the way in which the old job was loaded. If the first colour of the old job is equal to the second colour of the new job, then the situations described by table 2 are possible. Table 2 shows that in one out of three cases the operator can save a change in ink. If the second colour of the old job is equal to the first colour of the new job, then the situations described by table 3 are possible. Table 3 shows that in one out of three cases the operator can save a change in ink. If the second colour of the old job is equal to the second colour of the new job, then the situations described by table 4 are possible. Table 4 shows that an ink change saving will be possible for this case, irrespective of the way in which the old job was loaded.

Table 1 - Set-up alternatives for a two-colour old job, two-colour new job with the first colour shared

(W, X and Y are different colours, with the W lightest colour and Y the darkest)

Case	Job	Printing Station 1	Printing Station 2	Printing Station 3	Rinse	Ink-Up
1	**Old**	**W**	**Y**			
	New	W	X		1	1
			W	X	2	2
		W		X	1	1
2	**Old**	**W**		**Y**		
	New	W	X		1	1
			W	X	2	2
		W		X	1	1
3	**Old**		**W**	**Y**		
	New	W	X		2	2
			W	X	1	1
		W		X	2	2

Table 2 - Set-up alternatives for a two-colour old job, two-colour new job with the first colour of the old job identical to the second colour of the new job

(V, W and Y are different colours, with the V the lightest colour and Y the darkest)

Case	Job	Printing Station 1	Printing Station 2	Printing Station 3	Rinse	Ink-Up
1	**Old**	**W**	**Y**			
	New	V	W		2	2
			V	W	2	2
		V		W	2	2
2	**Old**	**W**		**Y**		
	New	V	W		2	2
			V	W	2	2
		V		W	2	2
3	**Old**		**W**	**Y**		
	New	V	W		1	1
			V	W	2	2
		V		W	2	2

Table 3 - Set-up alternatives for a two-colour old job, two-colour new job with the second colour of the old job identical to the first colour of the new job

(W, Y and Z are different colours, with the V the lightest colour and Z the darkest)

Case	Job	Printing Station 1	Printing Station 2	Printing Station 3	Rinse	Ink-Up
1	**Old**	W	Y			
	New	Y	Z		2	2
			Y	Z	1	1
		Y		Z	2	2
2	**Old**	W		Y		
	New	Y	Z		2	2
			Y	Z	2	2
		Y		Z	2	2
3	**Old**		W	Y		
	New	Y	Z		2	2
			Y	Z	2	2
		Y		Z	2	2

Table 4 - Set-up alternatives for a two-colour old job, two-colour new job with the second colour shared

(W, X and Y are different colours, with the W the lightest colour and Y the darkest)

Case	Job	Printing Station 1	Printing Station 2	Printing Station 3	Rinse	Ink-Up
1	**Old**	W	Y			
	New	X	Y		1	1
			X	Y	2	2
		X		Y	2	2
2	**Old**	W		Y		
	New	X	Y		2	2
			X	Y	1	1
		X		Y	1	1
3	**Old**		W	Y		
	New	X	Y		2	2
			X	Y	1	1
		X		Y	1	1

In tables 1 and 4 clearly the set-up time for the new job will be equal to the time required for one ink change only. However, in table 2 and 3 there is a 33 percent chance of a single ink change (case 3, table 2 and case 1, table 3) and a 66 percent chance of a double ink change (cases 1 and 2, table 2 and cases 2 and 3, table 3). In situations such as this where an answer cannot be obtained with absolute certainty, the technique will always choose the situation most likely to occur (the 66 percent probability cases in these instances). If a situation occurs where more than one scenario is possible with equal likelihood of occurrence, then the scenario with the shortest set-up time is chosen.

Tables 1, 2, 3 and 4 can be combined into table 5, as shown. Since the logical conditions for the 0.33 and 0.66 probability cases are identical, table 5 can then be condensed into decision table 6. To estimate the set-up time for a job the new job is compared to the previous job and either one rinse plus ink change are predicted, or two rinses and ink changes, indicated by the asterisk, are predicted. Note that table 6 forms one case (13) in the complete table (7), discussed in the following paragraph.

Table 5 - Condensed analysis for a two-colour old job and a two-colour new job with one colour shared

(OJ= Old Job, NJ= New Job, C= colour)

No. of colours Iden-Tical	IF				THEN		Probability
	No. of colours OJ=	AND No. of colours NJ=	AND	Source	No. of ink rinses =	No. of ink loads =	
1	2	2	OJC1=NJC1 and OJC1<>NJC2 and OJC2<>NJC1 and OJC2<>NJC2 **or** OJC1<>NJC1 and OJC1<>NJC2 and OJC2<>NJC1 and OJC2=NJC2	**Table 1.** **Table 4.**	1	1	1
			OJC1<>NJC1 and OJC1=NJC2 and OJC2<>NJC1 andOJC2<>NJC2 **or** OJC1<>NJC1 and OJC1<>NJC2 and OJC2=NJC1 andOJC2<>NJC2	**Table 2, case 3. Table 3, case 1.**	1	1	0.33
			OJC1<>NJC1 and OJC1=NJC2 and OJC2<>NJC1 andOJC2<>NJC2 **or** OJC1<>NJC1 and OJC1<>NJC2 and OJC2=NJC1 andOJC2<>NJC2	**Table 2, cases 1,2. Table 3, cases 2,3.**	2	2	0.66

Table 6 - Decision table for a two-colour old job and a two-colour new job with one colour shared

(Note that the asterix shows the option chosen in uncertain cases)

No. of colours iden-tical	IF			THEN		Probability
	No. of colours OJ=	AND No. of colours NJ=	AND	No. of ink rinses =	No. of ink loads =	
1	2	2	OJC1=NJC1and OJC2<>NJC2 **or** OJC1<>NJC1 and OJC2=NJC2	1	1	1
			OJC1=NJC2 **or** OJC2=NJC1	1	1	0.33
				2	2	0.66*

The strength of the technique is the fact that the colour of ink loaded on individual printer stations need not be recorded. Only colour combinations are considered. This is a very important advantage. If a scheduling system builds sequences of jobs and it records the status of each printing station's colour after a new job has been added to the sequence, then each prediction of the way in which the operator will load a new job needs to be 100% accurate for the next prediction to be of accurate. If the prediction for one case is not 100% accurate it is likely that more and more mistakes will follow. Furthermore, in an environment where the way in which a new job will be loaded is left to the operator to decide, it is impossible to always predict accurately how this will be done.

4 CASE STUDY

4.1 Manually Configured Corrugated Cardboard Printers in the Factory

The technique presented in this article is operating in a corrugated cardboard box factory as part of a production scheduling system. In this production scheduling system the printers' scheduler works as follows: it calculates the lead-time remaining and set-up time for each job available for processing on a specific printer. It then selects the job with the smallest set-up time for processing first. However, if the lead time remaining for another job is less than a critical limit (a variable that can be set), then this other job is selected first. The Shortest-In-First-Out priority rule is used as tiebreaker. Once a job has been selected, the process is repeated until all the jobs are sequenced. The technique presented in this article helps to calculate the set-up times for each job as part of the printer scheduling process.

The corrugated cardboard printers in the factory are mostly of the three printing stations, manually loaded type, but a few two-colour printers are also used. In this section only the three printing stations printer is discussed, because the principles apply equally well to the two printing stations printers, but in simpler form.

A three-colour printer consists of the following components: a feeder unit, three printing stations, a slotting unit, a die-cutting unit and a folding unit. To configure these printers for a new job the following components may need to be re-set:

a) A feeding unit that feeds cartons to the printing unit. This unit requires resetting whenever there is a change in the size of cardboard blank between jobs.

b) A printing unit that consists of three printing stations. The ink used for a completed job must be rinsed out of a printing station and another colour of ink loaded for the new job when a colour change is required. The stereos print the actual image. If the stereo is different for the new job, then the old stereo must be removed and the new stereo loaded.

c) A slotting unit that trims and slots grooves (that ease into cardboard blanks). The factory investigated produces so-called RSC's (regular slotted carton) and half-RSC's. Besides this, normal and so-called lock-back jobs, exist. If, there is a change from RSC to half-RSC or vice versa, or if there is a change from a normal job to a lock-back job or vice versa, then the slotting unit must be reset.

d) A die-cutting unit that cuts holes into cartons (breather holes, handle holes, etc.). If there is a change in die from one job to the next, then the die must be changed.

e) A folding unit that folds cartons. If the folding dimensions are different for the new job, the folding unit must be reset.

4.2 The Complexities of Estimating the Set-up Time for a Job on the Printers in the Factory

Designing a system for accurately predicting the set-up time for a job on these printers, in this case, is a complex undertaking. The reasons are the following:

a) There is no standard procedure for doing set-up operations. Even if the exact operations that must be done are known, it is still difficult to predict how long it will take, because certain set-up operations are sometimes done in parallel and other times not, depending upon the availability of personnel and adjunct resources.

b) The way in which colours and stereos are loaded on the printing stations of a printer depends upon the job that was produced beforehand, as explained previously.

c) Not only do identical colours and sometimes stereos between jobs influence the way in which a job is loaded, but also the darkness of colours. Loading a darker colour over a lighter one sometimes speeds up the rinsing process.

d) Colours are sometimes not rinsed out of a printing station, but kept in there even while a job not using the colour is being produced. This is done to save the number of rinses required.

e) Calculating all possible sequences between a given group of jobs that can be loaded, and finding a set-up time for each combination, is not feasible due to the number of combinations that exist for even a small group of jobs.

It should be clear to the reader that any system developed for predicting the set-up time for a specific job on these printers will probably never be entirely accurate.

4.3 The Database Required for Product Characteristics

The system implemented in the factory refers to a database containing all the characteristics of a job and compares those of two jobs, the last job printed (or being printed) and the new job considered, to make a prediction of the set-up time required for the new job. This database is called the product information file. For each product the product information file contains the following: colour 1, colour 2, colour 3, lock-back (yes or no), RSC (half or full), and die number. Colour 1 is the first colour that should be printed, colour 2 the second and colour 3 the third. The die number refers to the specific die required for that job.

4.4 Assumptions

The authors made several assumptions about set-up practice to make a prediction of the duration of a specific set-up operation possible. The assumptions were necessary to make the problem manageable. In reality these assumptions apply most of the time. The assumptions are:

a) The feeder and folding unit can be ignored for set-up time predictions because adjustments to them are done very quickly.

b) The printing, slotting and die-cutting units are always set up in parallel.

c) All jobs are one, two or three colour jobs (four and five colour jobs do occur but are uncommon at the factory investigated).

d) An operator will always load a new job so that the least amount of rinsing and stereo changes is required.

e) The colours for a job are always loaded on the printing stations in a predefined order. Lightest colour on the first printing station used, and progressively darker colours on subsequent printing stations. This order is specified in the product information file.

f) A colour change at a specific printing station is always accompanied by a stereo change at that station. The stereos used for different jobs are always different, therefore, even if a colour remains the same on a printing station (when a new job is loaded), the stereo must still be changed.

g) No distinction is made between tear-down and set-up operations. The former (such as rinsing and de-loading stereos) is treated as a set-up operation.

4.5 Calculating the set-up time for a new job

In this example case the second assumption in section 4.4 is allowed for by calculating the set-up times for each unit in parallel. The longest of the three is the set-up time for the specific new job.

The set-up time needed for the slotting and die-cutting units are standard for each case. Set-up times are determined by comparing the new job with the job last loaded on the specific machine and changes are made if needed.

To calculate the set-up time for the printing units the logical analysis illustrated in paragraph 3 was applied to compile table 7 (table 6 is included as case 13 in table 7). Table 7 is a summary of all the possible situations that can occur when loading a three-colour printer with either one, two or three-colour jobs. For each case the possible outcomes are displayed.

The technique for calculating the set-up time on the printing unit is as follows:

a) Determine if the two jobs are identical. If they are, the set-up time required is zero. If they are not go to step b)

b) From table 7 find the case that applies by matching the characteristics of the two jobs to the "IF" statements in the table.

c) Once the required operations are known the following formula is used for calculating the set-up time:

Maximum of [number of rinses x duration of one rinse +
number of ink-ups x duration of one ink-up +
number of colours of old job x duration of one stereo de-load +
number of colours of new job x duration of one stereo load]
or
[lock-back change duration + RSC change duration]
or
[die change duration]

The duration values of the various set-up operations for the factory printers investigated are displayed in table 8.

Table 7 - Ink changes required

(OJ= Old Job, NJ= New Job, C= colour)
(Note that the asterix shows the option chosen in uncertain cases)

CASE	No. of colOurs identical	IF: No. of colours OJ =	AND No. of colours NJ =	AND	THEN: No. of ink Rinses =	No. of ink Loads =	Probability
1	0	0	1		0	1	1
2	0	0	2		0	2	1
3	0	0	3		0	3	1
4	0	1	1	OJC1<>NJC1	1	1	1
5	1	1	1	OJC1=NJC1	0	0	1
6	0	1	2	OJC1<>NJC1 and OJC1<>NJC2	1	2	1
7	1	1	2	OJC1=NJC1 **or** OJC1=NJC2	1	2	0.33
					0	1	0.66*
8	0	1	3	OJC1<>NJC1 and OJC1<>NJC2 and OJC1<>NJC3	1	3	1
9	1	1	3	OJC1=NJC1 **or** OJC1=NJC2 **or** OJC1=NJC3	1	3	0.66*
					0	2	0.33
10	0	2	1	OJC1<>NJC1 and OJC2<>NJC1	2	1	1
11	1	2	1	OJC1=NJC1 **or** OJC2=NJC1	1	0	1
12	0	2	2	OJC1<>NJC1 and OJC1<>NJC2 and OJC2<>NJC1 and OJC2<>NJC2	2	2	1
13	1	2	2	OJC1=NJC2 **or** OJC2=NJC1	2	2	0.66*
					1	1	0.33
				OJC1=NJC1and OJC2<>NJC2 **or** OJC1<>NJC1 and OJC2=NJC2	1	1	1
14	2	2	2	OJC1=NJC1 and OJC2=NJC2	0	0	1
15	0	2	3	OJC1<>NJC1 and OJC1<>NJC2 and OJC1<>NJC3 and OJC2<>NJC1 and OJC2<>NJC2 and OJC2<>NJC3	2	3	1
16	1	2	3	OJC1=NJC3 **or** OJC2=NJC1	2	3	1
				OJC1=NJC1 and OJC2<>NJC2 and OJC2<>NJC3 **or** OJC2=NJC3 and OJC1<>NJC1 and OJC1<>NJC2	2	3	0.33
					1	2	0.66*
				OJC1=NJC2 and OJC2<>NJC3 **or** OJC2=NJC2 and OJC1<>NJC1	2	3	0.66*
					1	2	0.33
17	2	2	3	OJC1=NJC1 and OJC2=NJC3	1	2	0.66*
					0	1	0.33
				OJC1=NJC1 and OJC2=NJC2 **or** OJC1=NJC2 and OJC2=NJC3	2	3	0.33
					1	2	0.33
					0	1	0.33*
18	0	3	1	OJC1<>NJC1 and OJC2<>NJC1 and OJC3<>NJC1	3	1	1
19	1	3	1	OJC1=NJC1 **or** OJC2=NJC1 **or** OJC3=NJC1	2	0	1

Table 7 (continued) - Ink changes required

(OJ= Old Job, NJ= New Job, C= colour)
(Note that the asterix shows the option chosen in uncertain cases)

20	0	3	2	OJC1<>NJC1 and OJC1<>NJC2 and OJC2<>NJC1 and OJC2<>NJC2 and OJC3<>NJC1 and OJC3<>NJC2	3	2	1
21	1	3	2	OJC1<>NJC1 and OJC2<>NJC1 and OJC2<>NJC2 and OJC3<>NJC2	3	2	1
				OJC1=NJC1 and OJC2<>NJNJC2 and OJC3<>NJC2**or** OJC2=NJC1 and OJC3<>NJC2 **or** OJC2=NJC2 and OJC1<>NJC1 **or** OJC3=NJC2 and OJC1<>NJC1 and OJC2<>NJC1	2	1	1
22	2	3	2	OJC1=NJC1 and OJC2=NJC2 **or** OJC1=NJC2 and OJC2=NJC3 **or** OJC1=NJC1 and OJC2=NJC3	1	1	1
23	0	3	3	OJC1<> NJC1 and OJC2<>NJC2 and OJC3<>NJC3	3	3	1
24	1	3	3	OJC1=NJC1 and OJC2<>NJC2 and OJC3<>NJC3 **or** OJC2=NJC2 and OJC1<>NJC1 and OJC3<>NJC3 **or** OJC3=NJC3 and OJC1<>NJC1 and OJC2<>NJC2	2	2	1
				OJC1=NJC2 and OJC2<>NJC3 and OJC3<>NJC3 **or** OJC1=NJC3 **or** OJC2=NJC1 and OJC3<>NJC2 and OJC3<>NJC3 **or** OJC2=NJC3 and OJC1<>NJC1 and OJC1<>NJC2 **or** OJC3=NJC1 **or** OJC3=NJC2 and OJC1<>NJC1 and OJC2<>NJC1	3	3	1
25	2	3	3	OJC1=NJC1 and OJC2=NJC2 and OJC3<>NJC3 **or** OJC1=NJC1 and OJC3=NJC3 and OJC2<>NJC2 **or** OJC2=NJC2 and OJC3=NJC3 and OJC1<>NJC1	1	1	1
26	2	3	3	OJC1=NJC1 and OJC2=NJC3 **or** OJC1=NJC1 and OJC3=NJC2 **or** OJC2=NJC2 and OJC1<>NJC1 and OJC3<>NJC3 **or** OJC3=NJC3 and OJC1=NJC2 **or** OJC3=NJC3 and OJC2=NJC1	2	2	1
27	2	3	3	OJC1=NJC2 and OJC2=NJC3 **or** OJC2=NJC1 and OJC3=NJC2	3	3	1
28	3	3	3	OJC1=NJC1 and OJC2=NJC2 and OJC3=NJC3	0	0	1

Table 8 - Printer set-up operation duration's

Unit	Set-up Operation	Duration (minutes)	Product Information
Printing	Rinse	7	Colours
	Stereo de-load	3	Adjunct Resources
	Stereo load	4	Adjunct Resources
	Ink-up	3	Colour
Slotting	Lock-back change	6	Lock-back
	RSC change	10	RSC
Die-cutting	Die change	12	Adjunct Resources

4.6 Calculated Examples

The following two examples illustrate how the technique for calculating the expected set-up time works:

a) Assume that a job with the following product characteristics is loaded on the printer:

Colour 1:	White	RSC:	Y
Colour 2:	Green	Lock-back:	N
Colour 3:	Black	Die:	D1

Assume that we wish to calculate the set-up time for the following job:

Colour 1:	Yellow	RSC:	Y
Colour 2:	Green	Lock-back:	N
Colour 3:		Die:	D2

By comparing the product characteristics the following conclusions can be drawn: The die-cutting unit requires a set-up, thus 12 minutes (from table 8). The slotting unit requires no set-up, thus 0 minutes. The first job contains three colours, the second two colours and they share one identical colour. In table 7 this is case number 21. For the two jobs the Old Colour 2 is equal to the New Job Colour 2. This equates to the second part of case number 21 in table 7. This means that two rinses and one ink-up is required. Furthermore three stereo de-loads and two 2 stereo-loads are necessary. Therefore the set-up time for the new job is

Maximum of [2x7 + 1x3 + 3x3 + 2x4], [0], [12] = 34 minutes

b) Assume that a job with the following product characteristics is loaded on the printer:

Colour 1:	Blue	RSC:	Y
Colour 2:	Red	Lock-back:	N
Colour 3:		Die:	D1

Assume that we wish to calculate the set-up time for the following job:

Colour 1:	Grey	RSC:	N
Colour 2:	Blue	Lock-back:	Y
Colour 3:		Die:	D2

By comparing the product characteristics the following conclusions can be drawn: The die-cutting unit requires a set-up, thus 12 minutes (from table 8). The slotting unit requires a lock-back and an RSC change, thus 10 + 6 = 16 minutes (from table 8). The first job contains two colours, the second job two colours and the two jobs share one identical colour.

In table 7 this is case number 13. Further conclusions cannot be drawn using the information available, therefore the higher probability is selected. This means that two rinses and two ink-ups are necessary. Furthermore two stereo de-loads and two stereo-loads must be done. This estimate will be correct in 66% of the cases. Therefore the set-up time for the new job is

Maximum of [2x7 + 2x3 + 2x3 + 2x4], [10 + 6], [12] = 24 minutes

5. CONCLUSIONS

The technique presented is simple and can easily be computerised. The main advantage is the fact that it does not require status information about which colours are loaded on which printing stations when making an estimate of the set-up time for a job. Like any other tool attempting to predict the future it is not entirely accurate. The technique essentially reduces to the compilation of a look-up table based on an exhaustive analysis of all possible outcomes of a sequence for a particular physical set-up. It can be applied to predict sequence dependent set-up times for printers and similar processes.

REFERENCES

[1] Ashford R., Daniel R., Mixed integer programming in production scheduling: A case study, in *Optimization in Industry*, edited by Ciriani T.A. and Leachman R.C., Wiley, New York, 1993, 231-239.

[2] Reinecke A.E., *The development of a conceptual production scheduling system for use in a corrugated factory*, Unpublished M.Eng.(Industrial) thesis, University of Stellenbosch, 1994, 279pp.

[3] Yanney H.D., Kuo W., A practical Approach to a Multistage, Multiprocessor Flow-shop problem, *International Journal of Production Research*, 27(10), October 1989, 1733-1742.
