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SIMULATION OF JIT PERFORMANCE IN A PRINTING SHOP

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ABSTRACT

A medium sized UK based academic publishers own a subsidiary printing business. Presently the Academic Printers (AP) is experiencing productions line flow problems reducing the efficiency of the operation. Most of the problems are generated by the imbalanced workflow through the system. By implementing a JIT production planning system it is hoped that some of the production problems can be resolved. Using the simulation software a model was created to investigate the performance of the AP under a variety of operating conditions. Results showed that operating the system with JIT control would not produce economic performance improvements due to constraints applied by the printing process.

1 INTRODUCTION

Printing operations scheduling is a challenging task because of the many constraints imposed by the processing technology used. The current scheduling practices are mostly driven by the nature of the printing processes resulting in a considerable amount of work-in-processes (WIP), long waiting times and long lead times. Facing severe competition from South East Asian printing companies many western publishing companies have been forced to reconsider their traditional printing operations. Some of the publishing companies turned to subcontractors to eliminate at least some of the operation problems. However, this has created some other unpredictable problems such as quality, style and design.

Just in time (JIT) production is generally referred to as a manufacturing system for achieving excellence through continuous improvements in productivity and the elimination of waste. The ultimate goal of JIT is a 'balanced' manufacturing system, which is one that achieves a smooth rapid flow of materials through the system. A vast number of JIT-based research activities has been reported and described in various professional journals or conference proceedings. The early studies have concentrated more on philosophy and fundamentals of the JIT system investigating what JIT offers as a new production system and how it could be implemented (White et al, 1999; Yasin et al., 1997; Huson and Nanda, 1995; Fullerton and McWatters, 2001) The design and analysis studies concentrate more on shop floor implementation of JIT to control the production (Savsar and Al-Jawini, 1995; Baykoc and Erol, 1998; Pandey and Khokhajaikiat, 1996) These studies have been extended to Kanban allocation and the number of Kanban that should be used to create a streamlined production system (Upton, 1998; McMullen et al., 1998; Huang and Kusiak, 1998; Thesen, 1999; Savsar and Choueiki, 2000; Grosfield-Nir et al., 2000)

The AP is a medium-sized UK based printing company, which specializes in producing high quality academic texts for publishers worldwide. The system at present suffers from high WIP due to unbalanced production.

In this paper, we implemented a JIT shop floor control system through a simulation model to improve the performance measures in this printing company. We have created several real life-like scenarios to analyse the performance of the system under different operating conditions. The performance criteria considered are WIP, lead time, production rate, and throughput time.

For the purposes of this study the AP is simplified into its core printing activities. Other support roles carried out by AP such as plate manufacture and jacket and cover printing will be assumed to be external activities, which when required in the model will always be available.

2 SHOP FLOOR PERFORMANCE IN PRINTING OPERATIONS

Nomenclature

Job	-An order of a batch of books
Batch Size	-Number of books required in a Job
Cased Job	-Hardback book

Signature	-Bundle of pages (normally 32), which is created by folding and cutting a sheet and gluing a number of signatures together forms a book.
Sheet	-Large sheet of paper, which is run through the Printing Presses and has a signature printed on it by the Plates.
Plate	-An aluminium sheet having a printing surface produced by photographic deposition

2.1 The AP Scheduling System

AP can be described as operating a job shop facility as it produces a high variety of batch types and sizes in a make to order environment. A book may consist of only four different parts; pages, cover, binding and case but these are unique for every different type of book produced. The machines visited by a book during manufacture depend on the specification of the job, for example if the book is colour it has to be printed on a colour press. This adds to the complexity of the manufacturing process as the process flow varies from job to job.

Due to this high variability of both batch sizes and book types scheduling at the AP is a complex and difficult task. The AP Planning Department uses an assembly line balancing approach to scheduling. This technique is used in an attempt to utilize workstations to their full potential by trying to ensure that bottlenecks are not created and workstations are not starved by the workload in the system. The Planning Department tries to balance the workload in the system to maintain machine utilisation and control WIP. It is important to remember that every Job is unique and has different process times on a varying combination of machines. When a new job is sent to a workstation the workstation must be set-up to handle that specific job. Orders for jobs are received by the AP from the Planning Department in the form of a machine loading list. The loading list is broken down by machine name. When a press finishes printing a job it is assigned the preceding Job.

The system at present suffers from high WIP due to unbalanced production. A key factor in this is the high variability of the batch sizes and signature numbers in the Jobs. For example an order for 50,000 books would at present be printed in one transfer batch creating high WIP and an inflexible unbalanced environment. Machines become blocked with work and throughput times become unpredictable.

2.2 The Printing Process

The AP machine room, which contains the printing presses, it is broken down into three machine groups:

- **Quad Machines.** (2-Colour (B&W)). There are two Quad paper size presses Quad A and Quad B.
- **Colour Machines.** There are two B1 size 8-colour machines Col A and Col B both of these machines are identical.
- **2-Colour Machines**. There are four B1 size 2-colour machines M1, M2, M3, and M4. All of these machines are identical

Printing jobs are classified into job types depending on the machine they are assigned to.

2.2.1 Quad Jobs

1. All printing Jobs are printed one signature at a time; a plate can only be used once but has a life of 500,000+ sheet. When a new job is assigned to a press it has to undergo a First Make-Ready (First M/R) before printing can begin. A First M/R involves adjusting the machine for the paper size required, loading the required paper, filling ink reservoirs and fitting the plates for the first signature. After each signature is printed a Subsequent Make Ready (Sub M/R) is carried out to change the plates over for the next signature.
2. Printed sheets are stacked onto pallets and transferred to the controlled buffer to dry for 24 hours. This drying time is required to prevent smudging of the sheets during the folding process.
3. After the 24-hour period has elapsed the sheets are placed in a queue to be folded. The Quad signatures must be folded on one of three Quad-folding machines Quad Fold 1,2 or 3. Jobs are assigned to the first available folding machine by a First Come First Served (FCFS) selection rule. As with the presses when a new job is assigned to a folding machine it has to undergo a First M/R before folding can begin. Subsequent M/R for the folding machines simply involve signature change.
4. After all of the signatures in a Job are folded the Job is placed in the Bindery Queue. The route taken by the Job from here depends on the type of cover required, and the amount of signatures contained in the book. If the book contains more than 24 signatures or is to be sewn (increased strength) then it must be gathered before binding. Sewn jobs must be gathered on the Gathering machine all other books can be gathered on a redundant R-Type Binder if the Gathering machine is at capacity. Books are sewn on the Sewing machine. After gathering/sewing the Job is placed back into the queue for binding.
5. If the Job is paperback then it can be bound on either the S-type or R-type Binder. The R-type Binder is only used if no cased Jobs require proc-

essing. After binding paperback books are sent to dispatch.

6. If the Job is cased it must be bound on the R-type Binder before been cased by the Casing machine. After casing is complete the Job is sent to dispatch.

2.2.2 Colour Jobs

2- Colour Jobs and Colour Jobs follow the same process flow as Quad Jobs except that:

- 2-Colour Jobs are printed on one of the four 2-Colour machines. Colour Jobs are printed on one of the two Colour machines.
- Both Colour and 2-Colour Jobs and transferred to the Colour/2-Colour controlled buffer to dry for 24 hours.
- 2-Colour and Colour Job signatures are folded on one of five folding machines - C1, 2, 3, 4, or 5.

2.2.3 Process Constraints

There were several important constraints to consider when simulating the AP manufacturing process.

- Plates can only be used once as they are destroyed when removed from the Press. However they do have a life of 500,000+ pages.
- AP manufactures most of the Plates used in an in house facility. This facility has a limited capacity and would become overloaded if Plate production were to be increased significantly.
- The Plates represent a high proportion of the cost of printing a book.
- After printing sheets must be left to dry for 24 hours to prevent smudging when they are folded.
- The make-ready times for machines can be high when compared to the actual printing times.

Movement times between machines do not normally affect the manufacturing process.

3 THE SIMULATION MODEL

The simulation model of the AP was constructed by linking together 5 submodels which each perform a specific task.

3.1 Data Set

As discussed in Section 2 the type of jobs entering the APPD are extremely varied, batch sizes range between 500-60000+ and signature numbers range between 4-40+. The distribution of these values is not uniform, therefore, it was necessary to find a probability distribution that would represent the type of work the APPD prints.

Using previous manufacturing data (2001-2002) it is possible to build an overview of the type of work that the APPD system produces. By using the Input Analyser an analyst can quickly build mathematical expressions to represent a data set for use in Assign modules.

To represent a range of values for the batch size and the number of signatures contained in a job it is necessary to use a probability distribution. As the exact form of the distribution is not known but estimates for the minimum, maximum, and most likely values are available. Therefore, the triangular distribution is a suitable probabilistic distribution to represent the batch sizes.

Mean values from the 2001-2002 production figures, data from two weeks of production and the views of the staff were used to develop the distributions.

The five different scenarios that are implemented in the model are designed to test both the reliability of the model output and the systems performance under a range of operating conditions. In each scenario the distribution of the signature numbers change.

Although in reality it would be difficult to vary the distribution of the number of signatures entering the system, it does provide a useful indication of the accuracy of the model.

The batch size distributions are constant across the different scenarios. A mixture of fixed values and distributions represent a number of possible operating conditions that can be employed by APPD.

The following figures are the batch sizes adopted as part of fixed value batch size policy.

- 500, 1000, 1500, 2000, 2500, and 3000 are the fixed batch sizes used in each scenario. These values are used to try to identify a batch size where the workflow through the system becomes balanced and the performance criteria are optimised.
- 6000, 15000, 30000, and 60000 are the second set of batch sizes. These are used to investigate the performance of the system when the number of jobs is reduced but the volume of work in each job increases.

3.2 Distributions of Batch Sizes

- Tri (500,750,1000)
  The purpose of this distribution is to represent the system operating with a small transfer batch size.
- Tri (1000,1500,2000)
  Used to examine the systems performance with an increased transfer batch size quantity.
- Tri (500,1500,2000)

Used to examine the effects that very small batch sizes 500-1000 have on the performance of the system.

- Tri (1000,2000,3000)
  Used to examine the effects of a reduced number of M/Rs
- Tri (500,2000,3000)
  Used to examine the effects that very small batch sizes 500-1000 has on the performance
- Tri (500, 5000,10000)
  Used to examine the effects on the system when a range of large batch sizes is processed.
- Tri (2000,5000,10000)
  Used to examine the effects on the system when a large batch sizes are processed.

3.3 Scenarios

The following scenarios were created to analyse the system behaviours under different shop floor operating condition. Scenarios were created considering common practices seen in printing operations.

- **Scenario 1** – Current Environment (Tri 3,7,40)
  The initial simulation model try's to imitate the current operating system so that comparisons can be drawn.
- **Scenario 2** – Current Mean Number of Signatures (Tri 5,7,12)
  This distribution is used to represent the system when printing the most common signature quantities without the effects of the less common large signature quantities.
- **Scenario 3** – Current Environment with Reduced Spread (Tri 5-7-34)
  By reducing the extreme values for the number of signatures a more balanced system
- **Scenario 4** – Increased Mean with Reduced Spread (Tri 10,12,17)
  Increasing the mean number of signatures should reduce the number of First M/R carried out thus increasing the performance of the system
- **Scenario 5** – Increased Mean (Tri 10,12,34)
  In reality it would not be possible to constrain the number of signatures contained in the work produced to just a few values. However if significant performance benefits are found in increasing the mean value it could be economically viable to reduce the number of jobs with low numbers of signatures

3.4 Model Specifications

The AP system will be modelled using the Arena Simulation Software (Kelton et al., 2001). The model will try to imitate the current AP system as accurately as possible. Any assumptions made will be stated and where possible the effects that they could have on the validity of the model will be listed.

Any constraints that are applied to the actual system will be applied to the model.

All process times will be deterministic and will be calculated from AP benchmark values.

All data used in the model will be actual data collected from the system by AP.

The output from the model will reflect the performance measures currently used by the AP. This is to allow easy comparison between the current system and the proposed JIT system. The current performance measures are sheets (printed and folded) / time and books bound / time.

The set-up times of the machines in the APPD are currently very high compared to values that are normally associated with a JIT manufacturing system. For example the set-up time for the Quad A printing press is 50 minuets. However as the set-up times are relatively high on all of the APPD machines the effect of one machine unbalancing the process is reduced. However the flexibility of the system is compromised as the set-up times between products is high increasing non-productive time if batch sizes are small. Part of the JIT philosophy is a drive to continuously reduce set-up times this will greatly benefit the APPD.

The assign attributes submodel assigns the values for batch size and number of signatures to the passing entities. The batch size and the number of signatures contained in a job were initially set to the mean values gathered from the AP production records for 2001-2002, Table 1.

Table 1: Job Characteristics from 2001-2002 Production Figures

Machine Group	Average Sigs in a Job	Average Batch Size
Quad	6.12	1750
2-Colour	9.09	2000
Colour	7.30	2000

The entity type determines the machine type that is used to print the job. The different machine groups have varying set-up and throughput times, which are determined by the batch size and number of signatures of the Job. The machine running speeds are determined by the expression:

*Expression = 1st M/R + (Number of signatures in Job– 1 * Subsequent M/R) + Number of Signatures * (Batch Size of Job /Press Running Speed)*

The folding machine delay time is defined by the expression:

*Expression = 1st M/R + (Number of signatures – 1 * Subsequent M/R) + Number of Signatures * (Batch Size/Folding Machine Output)*

Entities leaving the two sets of folding machines are streamed together into the binding process submodel.

The Bindery Logic Submodel contains decide and assign modules which are used to control the route taken by the entity's through the different machines in the bindery.

The Bindery Submodel contains the gathering, sewing, casing and binding machines. The route taken by jobs through the submodel is defined by the decision logic in the Bindery Logic Submodel. The Binding machine delay time is defined by the expression:

*Expression = 1^{st} M/R + (Number of signatures – 1 * Subsequent M/R) + Number of Signatures * (Batch Size/Folding Machine Output)*

The graphical abilities of the software used allow the construction of displays, which show the outputs from a model during and after a simulation run. A graphical display was constructed to display the required performance measures.

The model was routinely shown to AP staff for comment and to identify any errors that the model contained.

To allow easy comparison between the current systems performance and alternative strategies the models outputs are in the form of the performance measures currently used by the AP. These performance measures are:

- Sheets printed by each machine group
- Sheets folded by each machine group
- Books produced
- WIP in the system
- Time taken to produce a book

The most important measure of performance is the number of books produced by the AP in a given time period. To increase profits the APPD try to maximise this value while still controlling the WIP in the system and the manufacturing Lead Time. In an optimum environment the number of books produced per period would increase, the lead times and WIP would decrease. The number of sheets printed and the number of sheets folded per period are used by the APPD as performance indicators to ensure that the machine rooms performance is been maintained.

4 IMPLEMENTATION OF A JIT SYSTEM AT APPD

A JIT approach was implemented by trying to identify a transfer batch size that jobs could be broken down into which allows the continuous flow of work through the system. This will achieve a production line that has a smooth flow of work passing through, bottlenecking at stations will be avoided and the overall WIP in the system will be reduced.

To be able to identify improvements in the APPD system it was necessary to create a simulation model that mimics the current operating environment. This model was then be used to make comparisons between the current operating strategy and alternative strategies developed in the scenarios. The outputs from the initial model were compared to actual performance outputs from the real system. The models performance outputs were approximately 25% higher than the actual systems. Each of the three entity types entering the model pass through an 'assign attributes module'. This module assigns the two attribute values 'batch size' and 'signature number'.

Identifying a quantity for the for batch sizes of jobs in the APPD system is vital in implementing a JIT system.

4.1 Unconstrained Transfer Batches

Unconstraint environment is effectively the environment that APPD operates at present. A full range of batch sizes from 500+ books is produced. Although this approach allows a full range of batch sizes to be available to the customer line balancing problems are common, as scheduling is extremely difficult. This approach is often used in make-to-order environments when set-up costs are high.

The majority of the work printed by the AP is received directly from a publishing house. The APPD do not have control over the type of work that is passed to them to print. The only constraint they apply is a minimum order quantity of 500 books per job. This has been found to be the minimum job size that is economic to print. Any batch size of 500+ books is therefore available to APPD customers. This does cause problems for the APPD as the jobs in the system have a high variability of batch sizes, which in turn leads to a high variability of processing times. In the present operating environment an order for a Job that has a batch size of 10,000 books would be processed as a single transfer batch of 10,000. However this does not have to be the case, an order for a Job that has a batch size of 10,000 books could be broken down into smaller transfer batches of 1000 books. Therefore to print the entire job 10 batches of 1000 books would be processed. There are three approaches that can be employed to specify the transfer batch size of jobs in the system.

4.2 Fixed Transfer Batches

Constraining the batch sizes of jobs in the system to a single quantity would be consistent with a JIT approach. However this would place constraints on the batch sizes available to APPDs customers as only multiples of the transfer batch quantity could be printed. A fixed quantity transfer batch can provide a balanced manufacturing system by ensuring a steady flow of work through the system. Process times for the transfer batches at each station can be standardised across all of the machines in the process therefore WIP will be minimised and bottlenecking at stations is avoided. Fixed transfer batches are not however always appropriate or possible, they limit the batch sizes available to the customers especially in make-to-order environments, as customers cannot choose exact batch sizes only multiples of the transfer batches.

4.3 Flexible Transfer Batches

By allowing a range of transfer batch sizes for example 1000-1500 books a greater range of batch sizes are available. The system is, therefore, more able to meet customer demands but could still be constrained enough to allow an effective line balancing strategy to be implemented. This is a more flexible approach especially in a make-to-order environment. Flexible transfer batch sizes require greater scheduling control to achieve a balanced system often a tolerance for higher levels of WIP is necessary.

4.4 Number of Signatures

Limiting the variability of the number of signatures contained in each book is a considerably more difficult strategy to implement. It would place restrictions on the number of pages a book could contain. It would simply not be feasible to fix the number of signatures in every book produced to a single quantity. This would mean that every book the APPD printed would be the same length massively restricting the number of different books that could be printed. Upper and lower limits could be placed on the number of signatures, although these limits would have to still allow the vast majority of the current work printed to continue to do so. Any strategy developed has to allow for the wide variability of signature numbers books contain.

5 RESULTS AND DISCUSSIONS

Results revealed that the batch size of Jobs processed has the greatest effect on the performance of the system. Results for the discrete batch size values below 1500 and above 6000 show a reduction in the performance of the system in terms of production output, Figure 1. Batch size values between 1500 and 6000 offer the highest output of books from the system, the greatest flexibility, Figure 2, the lowest WIP Figure 3, and the lowest throughput times Figure 4. Distributions of batch sizes produce the best performance when values are between 1500 and 6000. The system is able to cope extremely well with both a large range of batch sizes and discrete batch size values with little effect on performance, if a higher WIP level can be tolerated.

The number of signatures has a predictable effect on the system, the lower the number of signatures contained in a book the greater the number of books that can be printed. However the overall number of sheets printed remains fairly constant, Figure 5.

Results from the simulation demonstrated that implementing a JIT system, that is a system where small or fixed batch size Jobs flow in a balanced way through the production process would reduce the flexibility and performance of the AP system. The system is characterized by varying throughput and high set-up times, line balancing is almost

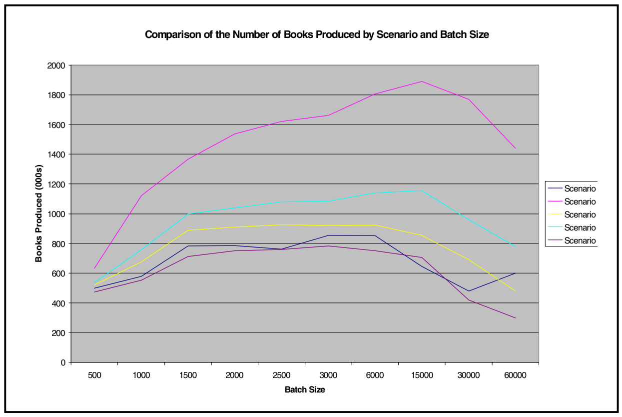

Figure 1: Comparison of the Number of Books Produced by Scenario and Batch Size

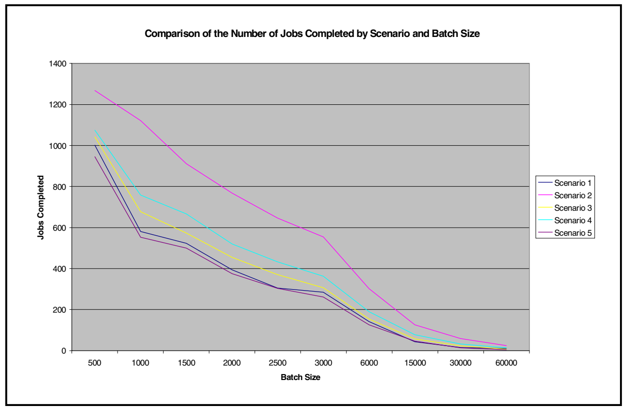

Figure 2: Comparison of the Number of Jobs Completed by Scenario and Batch Size

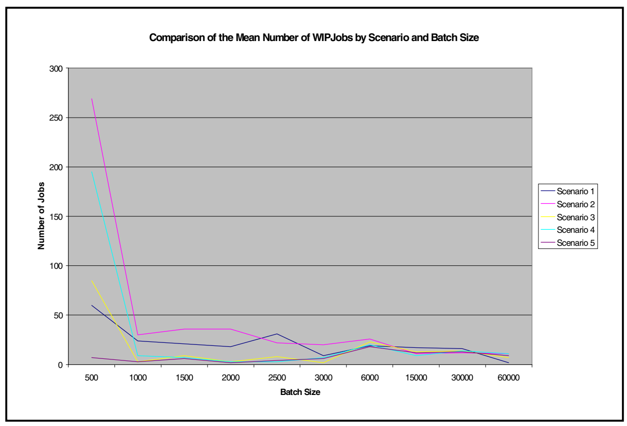

Figure 3: Comparison of the Mean Number of WIP Jobs by Scenario and Batch Size

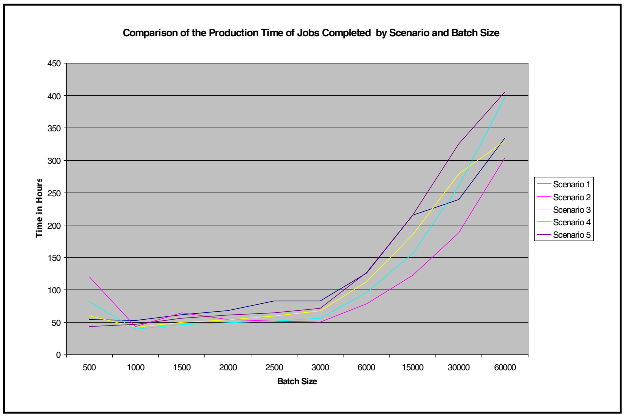

Figure 4: Comparison of the Production Time of Jobs Completed by Scenario and Batch Size

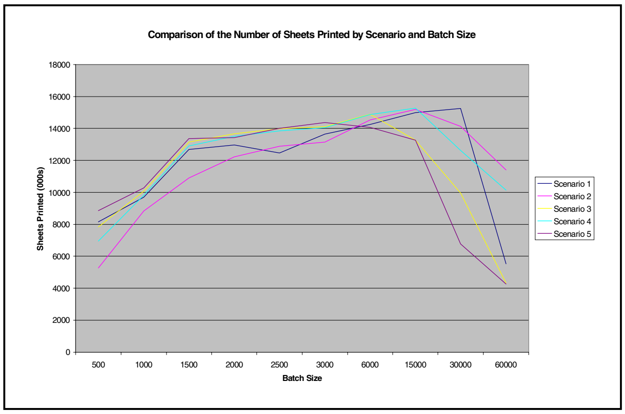

Figure 5: Comparison of the Number of Sheets Printed by Scenario and Batch Size

impossible if there is not some WIP to ‘buffer’ the different machines. Furthermore the model showed no significant performance improvements when fixed value batch sizes are used when compared to batch size distributions that include a wide range values.

The plates represent a large proportion of the cost of printing a book, if Jobs were broken down into transfer batches then a set of plates would be required for each transfer batch rather than a single set for the entire Job. This would dramatically increase the cost of printing.

6 CONCLUSIONS

JIT is a powerful planning and control technique which when used can produce huge benefits for an organization by considerably increasing the efficiency and effectiveness of a manufacturing system.

However in this study it has been found that implementing a JIT system at the AP would not increase the overall performance of the system. In fact is almost certain that in would reduce the profitability of the organization as a whole. Many of the machines in the AP system have high set-up times preventing a JIT approach from working. Furthermore by constraining the system to only print a fixed transfer batch size would lead to an excessive number of plates been used to print a single Job increasing the cost well beyond an economic level.

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