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Label Print Press Scheduling Consistency and Optimization: Hybrid Multilevel Scheduling of Label Packaging Printing Process Advancement for Polymer, Offset, Digital, Silkscreen, and Flexographic Press Systems

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Abstract: Packaging label printers seeks specialized printing press scheduling in benefiting both its press cost optimization while maintaining a consistency production process efficiently. Hybrid Multilevel Scheduling (HMS) answers both needs of guaranteed lead time stability and cost minimization. Five of the six existing press systems of label rotary press with roll to roll raw materials are being applied. Approximately 34,340 print orders over four years are being studied and analyzed. Each distinctive press system has its unique label press stations. It is proven that HMS Scheduling can be applied simultaneously across multiple press stations. Results have shown the significant factors that impacts the scheduling of print orders for packaging printer in the tradeoff. Algorithms of HMS Scheduling are provided to purpose as effective solution for the optimal printing scheduling outcomes.
Keywords: Packaging Printing Scheduling, Printing Cost Optimization, Print Press Process Consistency, Label Printing Scheduling

1. INTRODUCTION

Printing process improvement has recently transformed into an impacting bottleneck after the digitalization throughout the packaging print press. These prior successful instrument tools at the pre-press and press stage have let timely delivery and production lead time consistency apparent. Organizational innovation of technology implementation is both core competency and competitive strategy for printing manufacturers [1]. Job delays elimination together with tangible and intangible costs optimization is common obstacles throughout packaging printing manufacturers. Printers are in the made to order system with no pre-stock, stability in timely delivery is one of the necessity for packaging printing towards achieving higher customer satisfaction.

Most printers apply enterprise resource planning (ERP) and material resource planning (MRP) software to reduce process redundancy and uses the common traditional scheduling systems. However, the drawbacks of the current ERP and MRP softwares are not printing press designed and loses the opportunity in production efficiency and raw material cost optimization. Significant printing noise factors are impercipient throughout the current five distinctive packaging printing systems. The traditional scheduling systems finds difficulty in fulfilling the stability of print press processes. Consumers have forced the natural of their short product life cycle to the hands of printers to cope with a relatively zero job delays target.

2. MATERIALS AND METHODS

Materials used to analyze are the 34,340 printing job data of 13 label press stations, 5 printing systems, 2 post-press levels, and 9 post-press stations. There are four algorithms used in HMS Scheduling. The hybrid multilevel scheduling algorithms are to be performed continuously with the form of the 7 days Gantt chart of optimal printing order sequence. It is claimed that Gantt chart is “the earliest and best known type of control chart especially designed to show graphically the relationship between planned performance and actual performance.” [2]. This research will illustrate HMS Scheduling with the sequence of define conventional process, identify needs for change, and analyze the improvement process. Some repeating and large printing orders require printers to finish the job within the press process to save time and cost while shorter orders are done with the combination of the post-press stations. However, all the finished printing orders are to be inspected and packed before delivery.

After demonstrating the machines and printing systems used in the process phase of the scheduling algorithm, the type of orders flow in as data inputs is eventually essential. The printing orders used to simulate the scheduling algorithm are 78.65 percent of the popular CMYK process included jobs and 21.35 percent of non-CMYK jobs requests. The integration of systems throughout the press and post press process will enhance the flexibility to special and timely customer requests.

3. RESULTS AND DISCUSSION

(1) Define conventional process

The planning for printing process and execution are different to the common simple network diagram. As in figure. 1. shows the first to fourth processors states of queue, execution, and e-execution for the operation scheduling and the planning operation. An important notice would be printing orders may not be produced at a partial amount to the whole amount under certain circumstances. In fact, the processes are successfully at the executed or re-executed states with the sequence of production orders starting, transform to the next level waiting queue state, transform to its own level waiting queue state, turns from waiting state to running state, and terminates after post-press processes.

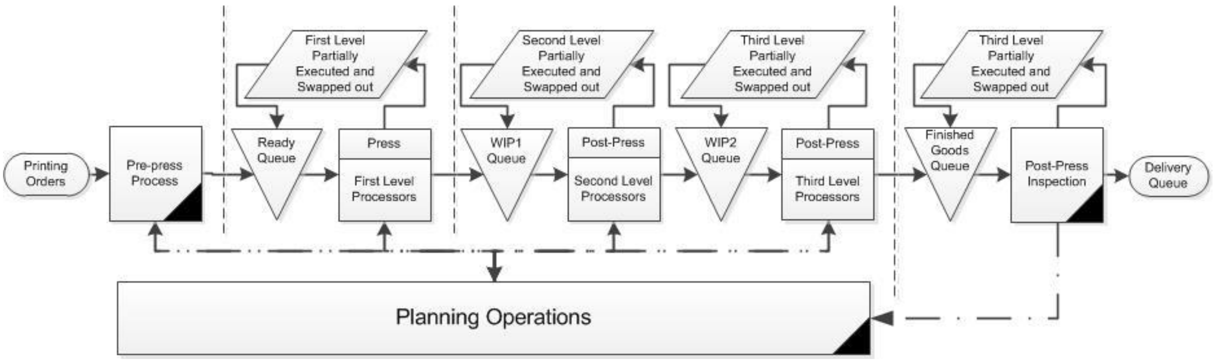

Figure.1 Press and Pre-Press Conventional Scheduling Process Flowchart

(2) Identify needs for change

All printers have time constraint on computation, but each task of orders are to be produced before its deadlines. Therefore, all printing scheduling algorithms should take concerns of the deadline at a prioritized and significant importance [3][4][5]. The current capabilities of flexibility results of conventional CPU Scheduling, MTTD Scheduling, and CAS Scheduling are shown in table.1 precisely. These indicating factors will be the key monitors of the results and impacts of a scheduling system. The Results has shown that order delays are relatively lower for MTTD Scheduling, and human errors are limited in CAS Scheduling. Therefore, a specially customized printing press scheduling will improve the results of the trade-off between cost optimization and delivery consistency.

Table.1 Performance indicators of conventional scheduling algorithm (quantity in thousands)

Scheduling Type	Year /Month	Job Types	Rush Orders (X1)	Order Shifts (X2)	Human Error (X3)	Production Productivity (X4)	Inspection Productivity (X5)	Order Delays (Y)
CPU (77 days)	TTL	Freq.	46	20	11	26	27	105
		QT.	3,735.20	2,926.8	308	1,942.29	5,853.25	15,226.54
MTTD (77 days)	TTL	Freq.	13	6	3	20	16	58
CAS (48 days)	2 to 3 months Estimated TTL	QT.	2,395.58	15,577.25	530	1,212.96	1,519.1	22,952.62

Printing job difficulty, as Press Productivity (X4) and Printing Set-up Time (X16), significantly impacts both job delay and printing cost optimization. The reverse relationship between Order Volume/Job (X9) to QC Defectives (X18) also implies that shorter orders impacts more printing costs. Similarities between Initial Lead Time (X8) and Actual Lead Time (X9) refers improving one of the two factors would impact both factors simultaneously. These direct and indirect related independent factors will be put into the consideration of this research paper of the HPS Algorithm analysis. The details of relationships between these independent factors are shown in table.2. The gap between the practice and the theory are also needed [6] .

Table.2 Correlation between independent factors of HMS Scheduling

Xi		*X2*	*X3*	*X4*	*X16*	*X7*	*X8*	*X12*	*X19*
		Rush Order Freq.	Rush Order Days	Press Productivity	Printing Setup Time	Order Volume	Initial Lead Time	Washing Time	Reproduction Volume
X2	Rush Order Freq.	1							
X3	Rush Order Days	0.768	1						
X5	Pump Productivity	0.218	0.268	0.911					
X7	Order Volume	-0.099	-0.2	-0.333	-0.456	1			
X9	Actual Lead time	-0.434	-0.286	0.086	0.056	0.216	0.648		
X10	Machine Break down (Freq.)	-0.347	-0.582	0.099	0.011	-0.097	-0.095		
X18	QC Defectives	0.038	0.172	-0.011	0.595	-0.481	-0.145	-0.002	
X20	Reproduction THB	0.063	0.099	0.074	0.257	-0.262	0.008	0.33	0.555
X21	Width Exactness	0.3	-0.127	0.051	-0.083	-0.016	-0.406	0.464	0.045

(3) Analyze the improvement process

This innovative HMS scheduling also requires a relatively alteration to the scheduling process. Figure. 2 shows the first to fourth processors states of queue, execution, and e-execution for the operation scheduling and the planning operation. In fact, the processes are successfully at the executed or re-executed states as of the bottom. Digitalization of scheduling would identify the bottleneck of the system that uses just-in-time and optimized-production strategies. Printers desire just-in-time and production optimization strategies due to relatively short lead time with numerous types of raw materials and printing press machines to handle with.

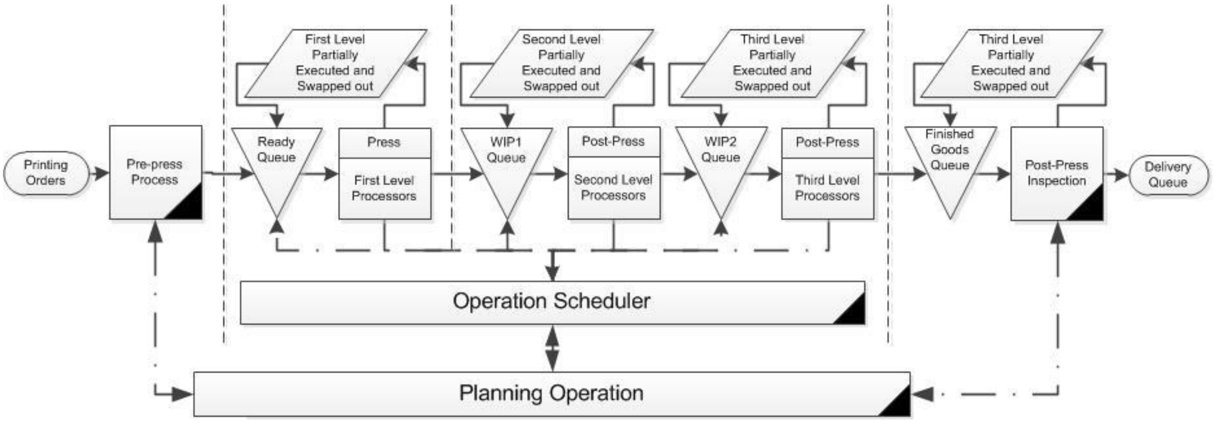

Figure. 2 Press and Pre-Press Hybrid Multilevel Scheduling Process Flowchart

As of the previous works of comparison for optimal scheduling algorithm, results, methods, and evaluations techniques are used to determine the best performed and robust scheduling algorithm [7][8]. This research has collected approximately 34,340 LLC print job data since 2017 to 2020 for the results analysis of HPS Scheduling. There are 21 independent factors with 6 dependent factors in table.3. It is obvious that job delay has a significant improvement as its frequency occurrence has managed to be minimized. Further relationships or statistical results of our research will be illustrated in the multiple regression section. Independent factor X1 to X21 and dependent factor Y1 to Y6 will be used symbolled.

Table.3 Data of independent factors of multiple regression for HMS Scheduling

ENG	Unit	Symbol	Year			
			2017	2018	2019	2020
Job#	/Job	X1	61,780.0	57,474.0	61,582.0	26,046.0
Rush Order	Freq.	X2	1,925.0	1,667.0	2,209.0	1,603.0
Rush Order	Days/ Rush Order	X3	13.2	11.9	30.9	29.4
Order Shift	Freq.	X4	200.0	352.0	416.0	310.0
Order Shift	Days/Freq.	X5	16.8	18.5	17.6	19.2
Job Difficulty	Easy=0%/ Normal=50%/ Hard=100%	X6	3.4	3.6	3.2	3.0
Order Volume	Piece/Job	X7	269,724.4	277,309.1	156,530.9	243,670.4
Initial Lead Time	Days Time	X8	52.7	57.7	52.6	52.8
Actual Lead Time	Days Time	X9	50.9	57.2	47.1	51.6
Machine Breakdown	Freq.	X10	30.0	34.0	20.0	12.0
Machine Breakdown	Hr. Time	X11	30.9	51.9	18.5	1,140.8
Washing Time	Special Color Freq.	X12	11,747.0	10,081.0	11,085.0	8,949.0
Employee Tardiness	Days Time	X13	107.3	223.5	236.3	186.1
Press Productivity	round/hr.	X14	40,082.0	42,474.7	30,269.0	29,935.0

Pump Productivity	round/hr.	X15	33,610.8	34,285.2	31,044.3	31,011.4
Printing Setup Time	hr./Job	X16	4.8	3.6	8.1	8.3
Pump Setup Time	hr./Job	X17	3.0	2.9	2.8	2.7
QC Defectives	THB	X18	1,795,583.0	1,386,600.0	3,545,912.0	3,635,168.0
Reproduction	Piece	X19	1,838,615.0	716,805.0	1,877,702.0	906,073.0
Reproduction	THB	X20	232,033.8	157,368.0	295,576.0	266,445.2
Width Exactness	Freq.	X21	2,069.0	1,743.0	1,891.0	1,549.0
Job Delay	Freq.	Y1	-	14.0	1.0	10.0
QC Due Delay	Freq.	Y2	15.0	107.0	49.0	78.0
Additional Paper	M^2	Y3	140,013.5	98,358.0	137,109.0	125,873.9
Additional Paper	THB	Y4	343,129.0	267,838.0	328,744.0	314,515.2
WIP Defectives	Piece	Y5	1,640,371.0	1,261,649.0	1,037,464.0	638,041.0
WIP Defectives	THB	Y6	610,967.0	582,236.0	441,753.0	278,925.0

Due to the complex combination of both vertical and horizontal flow of the packaging print press, several multiple linear regressions are required to run to show patterns and relationships. After running multiple linear regression statistics, accordingly based on the six dependent factors, there are 3 significant outcomes that pinpoints the precise factors controlled for optimal results. Other than that, printing scheduling ranking is also innovated as a part of the HMS printing scheduling algorithm.

Firstly, the MLR analysis on these independent factors to Due QC Delay is 82.85% significantly reliable based on multiple R value in table 4. These independent factors also prove their strong significant relationships in impacting the dependent factor of Due QC Delay (Y4) with a p-value of 0.000131309 as shown in table 20. The significant formula of p-value of 0.0001 stated below, is shown in table 5.

Table.4 Regression Statistics of independent factors (Xi) to Due QC Delay (Y4)

Regression Statistics	0.91024
Multiple R	**0.82853**
Adjusted R Square	**0.69135**
Standard Error	15.61097
Observations	37

Table.5 Multiple linear regression analysis of independent factors (Xi) to Due QC Delay (Y4)

ANOVA	df	SS	MS	F	Significance F
Regression	16	23,550.924	1,471.933	6.040	**1.3E-04**
Residual	20	4,874.049	243.702		
Total	36	28,424.973			

Other than the dependent factor of Due QC Delay (Y4), there is also the definite job delay dependent factor. However, Job Delays (Y2) includes the post-press quality control process that involves Acceptable Quality Limit (AQL) and 100% inspection time consuming processes that is not related to our studies. An efficient printing pre-press and press processes will contribute more lead time to such post-press stage. It is a promising result that independent factors X1 to X13 also impacts Job Delays (Y2) with a adjusted R square of 75.88% as stated in table 6 and a significant f-value of 1.7E-07 in table 7.

Table.6 Regression Statistics of independent factors (X1 to X13) to Job Delays (Y2)

Regression Statistics	0.91498
Multiple R	**0.83720**
Adjusted R Square	**0.75881**
Standard Error	23.50292
Observations	41

Table.7 Multiple linear regression analysis of independent factors (X1 to X13) to Job Delays (Y2)

ANOVA	df	SS	MS	F	Significance F
Regression	13	76,695.109	5,899.624	10.680	**1.7E-07**
Residual	27	14,914.452	552.387		
Total	40	91,609.561			

After emphasizing on the statistical analysis of the job delivery consistency, printing cost optimization are also analyzed with the follow statistical tests. Independent factor X1 to X13 are significantly related to Work-In-Process (WIP) piece defectives (Y5) with a f-value of 5.1E-15 in table 8 and table 9 with a promising reliability of 98.26% adjusted r square. These factors are both implied to impact the WIP piece defectives and the job delivery. A printing focused scheduling algorithm on delivery consistency and cost optimization are not trade off no more.

Table.8 Regression Statistics of WIP Defectives in piece (Y5)

Regression Statistics	0.99539
Multiple R	**0.99081**
Adjusted R Square	**0.98264**
Standard Error	21,188.10008
Observations	35

Table.9 Multiple linear regression analysis of WIP Defectives in piece (Y5)

ANOVA	df	SS	MS	F	Significance F
Regression	16	8.7E+11	5.4E+10	121.264	**5.1E-15**
Residual	18	8.1E+09	4.5E+08		
Total	34	8.8E+11			

Another cost optimizing indicator would be the dependent variable of WIP Defectives in amount (Y6). Although certain significant factors affecting WIP Defectives in amount duplicates with those of WIP Defectives Pieces(Y5), few additional factors are also indicated to influence cost optimization for printing scheduling. Factor of Pump Setup Time (X17) and Width Exactness between job shifts (X21) are also concerned as shown in table 10 and table 11.

Table.10 Regression Statistics of WIP Defectives in amount (Y6)

Regression Statistics	0.85329
Multiple R	**0.72810**
Adjusted R Square	**0.66219**
Standard Error	110,057.2674
Observations	42

Table.11 Multiple linear regression analysis of WIP Defectives in amount (Y6)

ANOVA	df	SS	MS	F	Significance F
Regression	8	1.1E+12	1.3E+11	11.046	**2.0E-07**
Residual	33	4.0+11	1.2E+10		
Total	41	1.5E+12			

To conclude the multiple linear regression analysis and correlation analysis, HPS Scheduling consists independent factors X2 to X21 except factor X17 are all significant to both printing delivery consistency and print press cost optimization objectives. Factor Pump Setup Time (X17), nonetheless, are solely significant to cost optimization scheduling. These are the significant factors and noises to HMS Scheduling.

The sequence of the four printing algorithms from Traditional Framwork Scheduling (TFS) stage, COS Scheduling and CAS Scheduling in the queue stage, to the stage of machine queue for HPS Scheduling are the same but expressed differently for the two packaging printing press systems. It proves that HPS Scheduling can be used across various printing systems simultaneously in figure 3. It is applied throughout flabed rotary (FBi), intermediate rotary (IRi), silkscreen flatbed rotary (SFi), full rotary (FRi), and Offet Rotary (Ori). Digital printing systems, however, do not need a scheduling systems due to its one-stage printing process but lacks the capability of mass production. There are also only four levels from printing level, die-cutting level (Di), slitting level (Si), and quality inspection level (QRi and QRi) respectively.

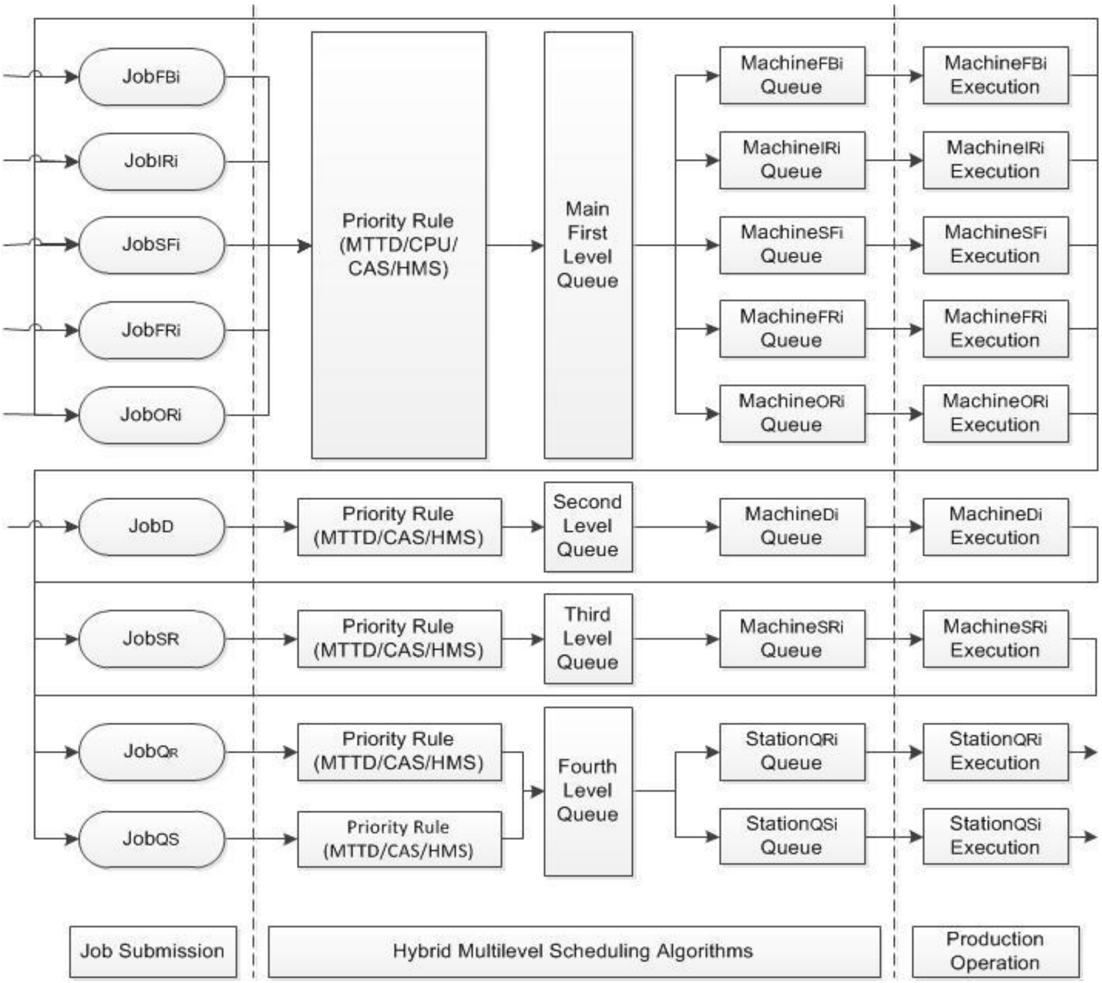

Figure.3 General Flow of Hybrid Perspective Scheduling algorithms of Label Print Press

(4) Discussion

As an effective solution to optimize both the tradeoff between print press cost optimization and printing delivery consistency, the HPS Scheduling fulfills the need for the modern printing press scheduling. Besides the two objectives, communication awareness scheduling for flexibility and traditional frameworks such as Shortest Job First (SJF), First Come First Servce (FCFS), and Minimum Time to Due Date (MTTD) are also taken into consideration. The relative algorithms with their weights and sequences are demonstrated below.

Let, H = Hybrid Perspective Scheduling,
O = Cost Optimization Scheduling,
A = Communication Awareness Scheduling, and
T = Traditional Framework Scheduling
Step.1 Run M
Step.2 OR(if TFS =< -3, initial Lead Time =< 5, A > 0)
run A + T, where A > T
Step.3 else, O+T, where O > T

where, A = Manual Communication Shifts due to Noise and Flexibility, run Fixed Priority Scheduling on certain job(s)
M = machine(s) fixed since initial start, do line balancing

$$\textbf{TPS Algorithm or T} = \frac{\begin{matrix}(6{,}550.58 + 16X_2\text{-}356.94X_3 + 0.09X_{14}\text{-}0.77X_{15}\text{-}676.42X_{16} + 0.03X_7 \\ \text{-}805.79X_8 + 325.16X_9 + 127.47X_{10} + 3.93X_{11}\text{-}2.14X_{12}\text{-}0.001X_{18}\text{-}0.002X_{19} \\ +0.05X_{20} + 107.65X_{13}\text{-}11.47X_{21})\end{matrix}}{100}$$

COS Algorithm or T

$$= \frac{0.98}{(0.98+0.66)}(22{,}561.95 + 4.35X_2\text{-}919.82X_3\text{-}1.36X_7\text{-}16.96X_8 + 10{,}305.85X_9\text{-}0.34X_{10} + 12{,}569.42X_{11}\text{-}3{,}658.97X_{12} + 505.74X_{13} + 18.9X_{14} + 16.29X_{15} + 0.89X_{16}\text{-}0.01X_{18}\text{-}0.19X_{19}\text{-}732.55X_{20})$$
$$+ \frac{0.66}{(0.98+0.66)}(255{,}324.43 - 0.4X_{14}\text{-}48.05X_{15}+173.25X_{16}+25{,}547.32X_{17} + 0.75X_{18} + 0.02X_{19} + 0.09X_{20}\text{-}51.17X_{21})$$

4. CONCLUSION

Hybrid Multilevel Scheduling solves the tradeoff between printing press cost optimization and job delay consistency for label printers under packaging printing industry. Significant factors impacting the two optimal goals are determined through correlation and various multiple linear regression statistic tests. HMS Scheduling not only meets print press cost optimization but also its flexibility to adapt to shorter lead time with rush orders and unpredictable order shifts. As a result, both scheduler labor time and packaging print press cost down targets are met. HMS Scheduling is a packaging printing press focused scheduling that renovates the improvements for packaging printers.

5. REFERENCES

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