Production programming on paper machines

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The purpose of 'Production Programming' is to determine the optimum production schedule on the paper machines in such a way that the cost of production is minimum or the profit is maximum. Though the conventional managers used to decide the programme on the basis of intuitive judgement, it is hardly optimal. In fact, the number of variables involved in a real-life problem is so large that it is humanly impossible to consider them simultaneously and take a correct decision on Production Programming. Hence, there is the need of a scientific approach to the same. The paper highlights the various aspects of a real-life problem of production programming and a solution to a truncated problem.

PROBLEMS :

A real-life production programming problem is a very complex one. Multiplicity of machines is one of the major reasons of complexity. Almost all big paper mills in the country have several paper machines. They are all different in capacity, (deckle) size, etc. Quality of paper produced are inter-changeable to some extent but not for all quality and machines. Moreover, the profitability of different quality of papers on different machines are different. All these lead to a complex product-mix problem wherein one has to decide what quality of paper is to be made in how much quantity on which machine to maximise the total profit. It must also take into account not only the availability of machines but also the availability of pulp, steam etc. which are hardly balanced.

The optimum production programme arrived at on the basis of above considerations have to be further modified due to several other obligations. For example, we may have to produce a specified quantity of white printing paper under Production Control Order. Sometime, we may have to make an uneconomic product due to other business considerations. All these have to be considered while arriving at an optimal solution.

Another aspect of the problem is the sequencing of quality of paper on a particular machine. Some grades and colour changes can be made through 'flying change'; others need complete wash-down resulting in loss of production. Hence 'change over' cost has to be considered. Also, attempts should be made to coincide wire/felt changes with quality change. It may be pointed out that sequencing of production for a few qualities depends on the condition of felts and wires. Some grades of paper require higher removing capacity of felts and wires. Hence they may be made when felts wires are new.

In majority of Indian Paper Mills, the wishes of sales department in manufacturing programme prevail. It is so much so that the production department has to make several changes on a machine resulting in poor productivity. It has been observed that on a particular day there has been as high as nine changes on a high speed machine. Quality and sizes of paper required are large in number. Moreover, the various size combination of paper to be made as per the advice of sales department do not always match the available machine deckle thereby resulting in higher trim-loss. And it is also known that the available machine deckle changes with life of felts and wire, calender roll condition, physical condition of machine etc. Hence it is dynamic in nature. An optimal solution has to take into account all these factors.

APPROACH

From the above discussion, it is clear that the production programming on paper machine is a very complex problem. And it needs a very scientific approach for its solution. Any programme based on intuition is bound to be far from an optimal one. From time to time, various authors have tried to solve the problem but partially only. Gotter Zaniker[1] have used combination generator and Linear programming for scheduling of a paper machine. Since the multi-machine problems with non-linear change-over

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cost is a complex one, attempt has been made here to solve only single machine problem at the initial stage by using Linear Programming (LP) approach.

LP APPROACH

The LP approach to the production programming problem is better explained with an oversimplified example.

Trim deckle of a paper machine is 70 inch. If 100, 250 and 80 reels of 16,20 and 22 inches width respectively are required, how to plan the slitting operation to minimise trim loss assuming that all the reels are of same diameter.

From the given data, it is clear that if one each of 16, 20 and 22 inch wide reels are cut from trimmed roll of 70 inch wide, there will be a side trim-loss of 12 inch $(=70-1\times16-1\times20-1\times22)$. Similarly, there will be many combinations of reels which can be cut from the parent roll but with different trim-loss. The various combinations along with the associate trim-loss are shown below. It may be pointed out that the combinations with trim-loss more than 10 inches are not considered here.

Parent roll = 70 inch wide

Width of reels (inch)	Cutting Plans								Reqd. reels (Nos.)
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	
16	4	3	3	1	0	0	0	0	400
20	0	1	0	0	3	2	1	0	250
22	0	0	1	2	0	1	2	3	80
Trim loss (inch)	6	2	0	10	10	8	6	4	430

It may also be noted that some combination may result into excess production of a particular reel size. For example, the cutting plan x_6 would turn out 45 reels of 22 inch width in excess of the requirement when the requirement of 20 inch width reels is met. This excess production is also a loss and may be included in the total trim-loss.

Since the various combinations or cutting plans give various trim-losses and different number of reels in one combination as shown above, the problem then boils down to the determination of that combination of cutting plans on the rewinder so that the total trim-loss is minimum; at the same time the requirement of reels is met.

The problem can be mathematically expressed as :—

Minimise the total trim-loss

$$x_0 = 6x_1 + 2x_2 + 0.x_3 + 10x_4 + 10x_5 + 8x_6 + 6x_7 + 4x_8$$

such that the following reel requirements are met :

$$4x_1 + 3x_2 + 3x_3 + x_4 \geqslant 100$$

$$x_2 + 3x_5 + 2x_6 + x_7 \geqslant 250$$

$$x_3 + 2x_4 + x_6 + 2x_7 + 3x_8 \geqslant 80$$

$$x\text{'s} \geqslant 0$$

This is LP formulation of the problem and can be solved through simplex technique[2]. The solution with successive iterations are shown in Annexure I.

From the annexure, it is seen the optimal cutting plan is $x_3 = \frac{100}{3}$, $x_5 = \frac{250}{3}$ and $x_8 = \frac{140}{9}$ which satisfies the reel requirement as follows :

Table 2

		Reel width 16″	20″	22″
x_3	$16\times3 \times \frac{100}{3} =$	100	—	—
	$22\times1 \times \frac{100}{3} =$	—	—	$\frac{100}{3}$
x_5	$20\times3 \times \frac{250}{3} =$	—	250	—
x_8	$22\times3 \times \frac{140}{9} =$	—	—	140/3
	No. of reels =	100	250	80

The total number of rolls required is $\frac{1190}{9}$ and the trim loss works out to be 9.68% $\left(=\frac{8060}{9}\times\frac{9}{70\times1190}\times100\right)$. A non-integar solution is assumed to be acceptable for this example.

The final iteration of simplex technique also gives a few more useful information. It tells us about the product (in this case of reel) whose requirement may be increased/decreased to effect economy. A systematic sensitivity analysis provides a host of other useful clues for better decision in the face of likely changes of various parameters.

CASE STUDY

A study has been conducted in a large integrated Pulp and Paper Mill to improve the production programme. Production data indicates that 60 gsm Cream-wove quality of paper accounts for the highest pe centage (about 30%) of total production, followed by 64 gsm SSS Maplitho. Hence, it has been decided to study the 60 gsm Cream wove paper production on a high speed machine. Analysis of production data on this machine for six months reveals that only 10 sizes of paper out of 23 sizes account for 95.12% of total production as shown in Annexure-II. Hence, attempt should be made to concentrate on first ten sizes and eliminate the remaining sizes as far as possible from manufacturing programme. Also, the average size changes per day worked out to be a little more than 3; and on a particular day it has been as high as 9. Since, frequent size changes effect production and trim-loss, it should be made as little as practicable.

The LP approach explained earlier has been applied for the said 10 sizes accounting for 95.12% of total production. Unlike the previous one, this is two dimensional problem (breadth x width) with related complexities. Computer facility has been availed of to solve the problem and the resulting trim-loss works out to be 1.43%. This is the acceptable lower limit of trim loss with above sizes and requirement of paper.

Since production programming is a regular task, it is costly to go to the computer centre every time for the optimal solution. Also, there are fewer varieties in a monthly production programme. Hence, it has been decided to solve the problem manually with loss of accuracy. The resulting solution for the same problem is shown in Annexure-III.

From the annexure, it may be observed that with the proposed cutting plan, the trim loss works out to be 2.01%. Though this is higher than the computerised LP solution, this has been accepted in view of regular and high computer charges and other related expenses.

The validity of the proposed method has been verified with the actual trim-loss of three qualities of paper produced during a month (Annexure IV). From the annexure, it may be observed that the trim-loss can be reduced from the existing 4.03% to the proposed 1.70%. It may be noted that with increased production for some varieties, the trim loss can be reduced further. For example, the trim-loss on SSS M/L 64 gsm (Annexure IV) can be reduced to 1.36% with excess production of 61 × 91 cm size by 26.28 MT which may by treated as stock production. The last two simplex iterations along with combinations and optimum results for SSS M/L 64 gsm paper production is shown in Annexuae V.

Subsequently, the cutting plans have been made and implemented. It has been observed that the actual trim-loss has been reduced to a level of 2.26%. And it would come down to the proposed level with regular follow-up.

CONCLUSION

Production programming in a multi-machine plant of different capacity and capability is a very complex one. Though a complete solution is necessary, it is worth to find solution to trim-loss and other truncated problem. It also gives direction to desirable change in the production programme.

It may be mentioned that the larger the period for which production is desired, the lower will be the trim-loss. Instead of monthly programme, if it is made weekly or daily, the loss will be higher. Hence, sales department should supply the requirement at least for a month at a time without frequent changes. Also, some of the sizes which do not match the deckle should be avoided.

If the products are interchangeable on machines, the trim-loss gets reduced further. Hence, selection of propuct quality vis-a-vis available machine capability is important.

Since deckle size reduces with time, optimum cutting plan also changes. Attempt should be made to regain the original deckle size.

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SIMPLEX ITERATION

	X_0	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	S_1	S_2	S_3	R_1	R_2	R_3	Solution
X_0	1	—6	—2	0	—10	—10	—8	—6	—4	—16	—20	—22	—M	—M	—M	0
R_1	0	4	3	3	1	0	0	0	0	—1	0	0	1	0	0	100
R_2	0	0	1	0	0	3	2	1	0	0	—1	0	0	1	0	250
R_3	0	0	0	1	2	0	1	2	3	0	0	—1	0	0	1	80
X_0	1	4M-6	4M-2	4M	3M-10	3M-10	3M-8	3M-6	3M-4	—M-16	—M-20	—M-22	0	0	0	430 M
R_1	0	4	3	(3)	1	0	0	0	0	—1	0	0	1	0	0	100
R_2	0	0	1	0	0	3	2	1	0	0	—1	0	0	1	0	250
R_3	0	0	0	1	2	0	1	2	3	0	0	—1	0	0	1	80
X_0	1	$-\frac{4M}{3}-6$	—2	0	$\frac{5M}{3}-10$	3M-10	3M-8	3M-6	3M-4	$\frac{M}{3}-16$	—M-20	—M-22	$-\frac{4}{3}M$	0	0	$\frac{890}{3}M$
X_3	0	4/3	1	1	1/3	0	0	0	0	—1/3	0	0	1/3	0	0	100/3
R_2	0	0	1	0	0	3	2	1	0	0	—1	0	0	1	0	250
R_3	0	—4/3	—1	0	5/3	0	1	2	(3)	1/3	0	—1	—1/3	0	1	140/3
X_0	1	—70/9	M-10/3	0	—6	3M-10	$2M-\frac{20}{3}$	$M-\frac{10}{3}$	0	—140/9	—M-20	—70/3	$-\frac{M}{3}-\frac{4}{9}$	0	—M+4/3	$\frac{750}{3}M+\frac{560}{9}$
X_3	0	4/3	1	1	1/3	0	0	0	0	—1/3	0	0	1/3	0	0	100/3
R_2	0	0	1	0	0	(3)	2	1	0	0	—1	0	0	1	0	250
X_8	0	—4/9	—1/3	0	5/9	0	1/3	2/3	1	1/9	0	—1/3	—1/9	0	1/3	140/9
X_0	1	—70/9	0	0	—6	0	0	0	0	—140/9	—70/3	—70/3	$-\frac{M}{3}-\frac{4}{9}$	$-M+\frac{10}{3}$	$-M+\frac{4}{3}$	8060/9
X_3	0	4/3	1	1	1/3	0	0	0	0	—1/3	0	0	1/3	0	0	100/3
X_5	0	0	1/3	0	0	1	2/3	1/3	0	0	—1/3	0	0	1/3	0	250/3
X_8	0	—4/9	—1/3	0	5/9	0	1/3	2/3	1	1/9	0	—1/3	—1/9	0	1/3	140/9

$X3=\frac{100}{3}$, $X5=\frac{250}{3}$, $X8=\frac{140}{9}$ Total no. of rolls $=\frac{1190}{9}$ Loss = 9.68%

S's = Slack variables, R's = Artificial variables, M=Large penalty

ANNEXURE—II

CREAM WOVE PRODUCTION

Sl. No.	Size (Cm × Cm)	%	Cum. %	Sl. No.	Size (Cm × Cm)	%	Cum. %
1.	58.5×91	32.30	32.30	11.	65×80	1.24	96.36
2.	51×76	28.00	60.30	12.	43×69	0.96	97.32
3.	76×102	7.87	68.17	13.	56×71	0.95	98.27
4.	61×68	7 60	75.77	14.	40×65	0.37	98.64
5.	45.5×56	6.64	82.41	15.	42×67.5	0.23	98.87
6.	54×71	3.48	85.89	16.	57×89	0.22	99.09
7.	51×66	2.50	88.39	17.	33.5×42	0.21	99.30
8.	56×91	2.39	90.78	18.	56×76	0.17	99.47
9.	43×67.5	2.26	93.04	19.	63×76	0.17	99.64
10.	63.5×78.5	2.08	95.12	20.	61×76	0.16	99.80
				21.	66×102	0.10	99.90
				22.	45.5×66	0.08	99.98
				23.	43.5×56	0.02	100.00

ANNEXURE—III

PRODUTION PROGRAMME ON PAPER MACHINE CUTTING PLAN

At Rewinder Width of Reels (Cm)		At Cutter I			At Cutter II		
1st Reel	2nd Reel	Size (Cm × Cm)	Trim (Cm)	Production %	Size (Cm × Cm)	Trim (Cm)	Production %
182	124	2×91×58.5	—	11.01	2×58.5×91	7	7.08
176	130	3×58.5×91	0.5	2.87	2×63.5×78.5	3	2.08
124	182	2×61×86	2	7.60	2×91×58.5	—	11.34
153	153	3×51×76	—	14.00	3×51×76	—	14.00
153	153	3×51×66	—	1.25	3×51×66	—	1.25
102	204	1×102×76	—	2.62	2×102×76	—	5.25
168	138	3×56×91	—	2.81*	2×67.5×43	3	2.26
162	144	3×54×71	—	1.85	2×71×54	2	1.63
137	169	3×45.5×56	0.5	2 98	3×56×45.5	1	3.66
				46.99			48.55

Total Trim Loss = 2.01%
Machine deckle = 310 Cm, Trim Deckle = 306 Cm, Trim deckle of Cutter = 204 Cm
A fixed trim of 1 cm on both sides of each reel is provided for even edge
*Production is 0.42% more than requirement. This is not treated as loss here.

ANNEXURE—IV

CUTTING PLAN FOR A MONTH

Quality	At Rewinder Width of reel (Cm)		At Cutter I			At Cutter II			Trim Loss %		Total Prod. (MT)
	1st reel	2nd reel	Size (Cm× Cm)	Trim (Cm)	Production (MT)	Size (Cm× Cm)	Trim (Cm)	Prod. (MT)	Present	Proposed	
SF M/L Ptg.	152	152	2×76×102	—	83.8	2×76×102	—	83.8	4.22	1.80	242.5
60 GSM	182	122	2×91×58.5	—	45.6	2×58.5×91	5	29.3			
SSS M/L	152	152	2×76×102	—	31.6	2×76×102	—	31.6	3.90	1.59	264.9
64 GSM	152	152	2×76×51	—	36.3	2×76×51	—	36.3			
	182	122	2×91×58.5	—	23.4	2×58.5×91	5	15.1			
	122	182	2×61×91	—	31.7	2×91×58.5	0	47.3			
	198	102	3×66×51	—	7.6	1×102×76	4	3.9			
SSS M/L	152	152	2×76×102	—	6.5	2×76×102	—	6.5	3.89	1.75	68.6
95 GSM	182	122	2×91×58.5	—	11.7	2×58.5×91	5	7.5			
	204	100	2×102×76	—	24.5	1×100×70	0	12.0			
			Total		302.7			273.3	4.03	1.70	576.0

M/c Deckle = 308 cm, Trim Deckle = 304 cm, Trim deckle at cutter 204 Cm.

"Production Programming on Paper Machine" SSS M/L 64 gsm Production

Annexure—V

	X_0	X_1	X_2	X_3	X_4	X_5	X_6	S_1	S_2	S_3	S_4	S_5	R_1	R_2	R_3	R_4	R_5	Solution
X_0	1	0	0	0	0	—7.42	0	0	0	—1.65	+2.43	—2.04	—M	—M	-M+1.65	-M—2.43	-M+2.04	81.52
X_1	0	1	0	0	0	0	0	-.33	0	0	0	0.17	0.33	0	0	0	-.17	20.80
X_2	0	0	1	0	0	0	0	0	-.33	0	0	0	0	0.33	0	0	0	23.88
X_4	0	0	0	0	1	—1.49	0	0	0	—.33	(0.49)	0	0	0	0.33	—.49	0	13.18
X_3	0	0	0	1	0	2.49	0	0	0	0	—.80	0	0	0	0	0.80	0	25.44
X_6	0	0	0	0	0	0	1	0	0	0	0	—.51	0	0	0	0	0.51	3.84
X_0	1	0	0	0	-4.95	-.03	0	0	0	—.02	0	—2.04	—M	—M	-M+.02	—M	-M+2.04	16.15
X_1	0	1	0	0	0	0	0	-.33	0	0	0	0.17	0.33	0	0	0	-.17	20.80
X_2	0	0	1	0	0	0	0	0	-.33	0	0	0	0	0.33	0	0	0	23.88
X_4	0	0	0	0	2.04	-3.04	0	0	0	-.67	1	0	0	0	0.67	-1	0	26.90
X_3	0	0	0	0	1.63	-2.43	0	0	0	-.54	0	0	0	0	0.54	-.80	0	46.96
X_6	0	0	0	0	0	0	1	0	0	0	0	-.51	0	0	0	0	0.51	3.84

Combinations

	X_1	X_2	X_3	X_4	X_5	X_6
76×102	2	—	—	—	—	—
76×102	2	—	—	—	—	—
76×51	—	2	—	—	—	—
76×51	—	2	—	—	—	—
91×58.5	—	—	2	2	—	—
58.5×91	—	—	—	2	—	—
61×91	—	—	2	—	2	—
91×61	—	—	—	—	2	—
66×51	—	—	—	—	—	3
102×76	—	—	—	—	—	1
Trim (cm) Loss	0	0	0	5	0	4

Optimal Solution

	Size	Prod. (MT)	Size	Prod. (MT)	Loss (cm)
X_1 = 20.80	2×76×102	31.62	2×76×102	31.62	0
X_2 = 23.88	2×76×51	36.30	2×76×51	36.30	0
X_3 = 46.96	2×91×58.5	85.48	2×61×91	57.30*	0
X_6 = 3.84	2×66×51	7.60	1×102×76	3.92	4
S_4 = 26.90					
		161.00		129.14	

*61×91 size is produced more

Trim Loss = 1.35%