Material Flow Optimisation for Multistage, Multiproduct Parallel Lines

Kailash Bhosale

December 15, 2022

Material Flow Optimisation of Multistage, Multiproduct Parallel Lines

K. C Bhosale[1],

[1]Department of Mechanical Engineering, Sanjivani College of Engineering, Kopargaon.

Savitribai Phule Pune University, Pune, Maharashtra. India.

Bhosale_kailash@yahoo.co.in,

Bhosale K.C.ORCID ID = orcid.org/0000-0002-9429-6572

K.C. Bhosale is currently working as Associate Professor at Sanjivani College of Engineering, Kopargaon. He received his Bachelor's degree from Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, his Master's degree from Savitribai Phule Pune University, Pune and Ph. D. from K.K. Wagh Institute of Engineering Education and Research, Nasik, Savitribai Phule Pune University, Pune, Maharashtra, India. He has 9 years of Industrial experience and 14 years teaching experience. His research interest includes Production planning and scheduling.

Declarations

Funding : Not Applicable

Conflicts of interest/Competing interests: All the relevant research papers are cited

Availability of data and material: Not Applicable

Code availability: Not Applicable

Ethics approval: Plagiarism is checked and it is found within the limit

Consent to participate: Not Applicable

Consent for publication: Both authors have given consent for publication

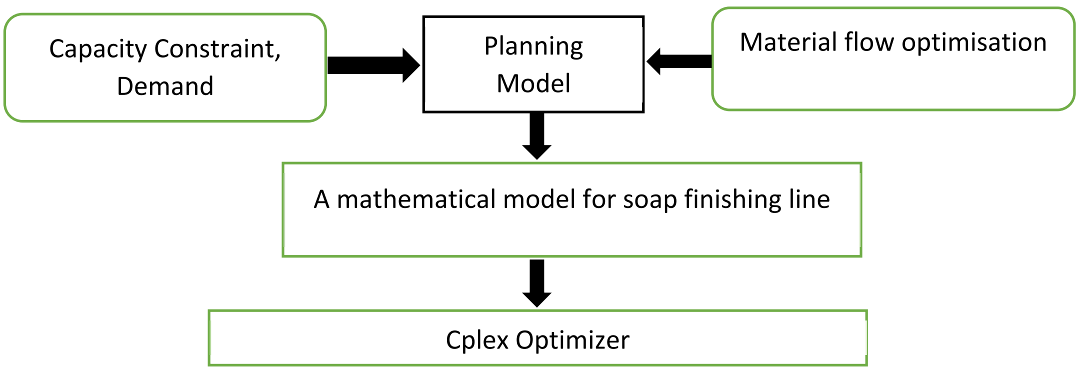
Material Flow Optimisation for Multistage, Multiproduct Parallel Lines

Abstract:

In the production planning phase, long-term decision problems are addressed. In this phase, the demand of the products is fulfilled by considering the production capacity, available time and available manpower. The demand of the products is determined by Monte-Carlo simulation method. The objective function is considered to minimise material flow time. A case study based on soap finishing line which is related to multistage, multiproduct parallel line is selected. The mathematical model is formulated as mixed integer nonlinear programming. The CPLEX optimisation solver is used to find the optimum solution.

Keyword: Production planning, Soap finishing line, mixed integer nonlinear programming, Cplex.

Graphical Abstract:



1. Introduction

In the process industries, multiple products are produced on parallel lines such as fast-moving consumable goods (FMCG). The flexibilities as process flexibility, product flexibility, routing flexibility are observed in the process industries. The market demand of these products is small and fluctuating. So, it is not possible to purchase a special processing unit for manufacturing each and every product. To achieve the optimum solution for the real-world problem, a mathematical programming model is formulated. This mathematical model is developed in the form of mixed integer nonlinear/linear programming model (MINLP / MILP). (Stecke, 1983; Gupta and Gupta, 1988; Sahinidis and Grossmann, 1991a, 1991b; Zhang and Yan, 2005; Anli, Caramanis and Paschalidis, 2007; Bley *et al.*, 2012) have considered non-liner programming model while (Kopanos, Puigjaner and Georgiadis, 2010; Georgios M. Kopanos, Luis Puigjaner, 2011; Xue *et al.*, 2011; Yan, Wan and Xiong, 2014) have considered linear mathematical model. This mathematical model is formulated by considering the objective function such as to minimise the total time which comprises of processing time, set up time, recycle time and changeover time etc.

The different time units are calculated by collecting the data from the real-life problems. The optimum time is calculated by allocating the products to the machine in the sequence and by considering the start and finish time.

Material flow can be defined as the time required from the start of the first operation to the finish of the last operation in the system. For the production planning problem, material flow consists of three-time elements such as processing time, set up time and recycle time. Processing time is calculated by considering the time required to perform different operations on different machines. The time required to change the packaging material, cleaning of the parts is considered as setup time. The time required to start equipment after each planning period is taken as recycle time (Bhosale and Pawar, 2018).

This research work is based on real-life problem of material flow optimisation of production planning problem of a soap finishing line. For developing a mathematical model for a soap finishing line, the problem is considered as a flow shop problem. The mathematical model is based on mixed integer non-linear programming (MINLP). The objective function is considered to minimise total of production time, setup time and recycle time. The constraints considered are total time available and capacity of the finishing lines.

The main contribution of this work is as follows:

- Considered a material flow optimisation problem of a soap finishing line which is a multistage, multiproduct parallel lines problem.
- A mixed integer non-linear programming (MINLP) mathematical model is formulated for production planning problem.

This work is organized as follows. In section 2, a brief review of the literature based on production planning problem and material flow optimisation problems is carried out. In the section 3, mathematical model is formulated for production planning model as mixed integer non-linear programming. In section 4, a case study problem based on soap finishing line is considered.

In the next section a brief literature review is carried out.

2. Literature review

Gaglioppa et al. (2008) have considered multitasking and multistage problem of a batch manufacturing process plant. The objective considered to minimise total of production cost, setup cost and inventory holding cost while the constraints are production capacity and availability of processing units. Maravelias and Sung, (2009) have considered problem related to the process industries in which production is distinguished into two parts i.e. continuous and batch production. In the continuous production, few products having stable demands with similar routing are produced while in batch production, products to be produced are large in number and demand varies with time. Kopanos et al. (2010) have considered a real-life problem of a yogurt production. They considered objectives to minimise inventory cost, operating cost, fermentation recipe cost, unit utilization cost, product family changeover cost and the constraints are timing and sequencing, allocation and sequencing, mass balance, sharing common resources. They proposed a mixed discrete/continuous MILP. Kopanos et al. (2011) have considered a problem of a beer manufacturing company. They considered objectives to minimise total cost of inventory, backlogs, changeover and set up while material balance, family allocation, family sequence and timing, family changeover, production time are considered as constraints. Yan et al. (2014) have considered multi-period production planning problem with set up and mixed batch. They have considered objectives to minimise production cost, inventory cost, penalty cost and constraint was machine capacity. Chu et al. (2015) have considered a multistage manufacturing plant with a production uncertainty. The objective is to minimise total of inventory and set up cost and constraints are customer demand, production quantity. Shi and You (2015) have considered nonlinear formulation for process plant of methyl methacrylate (MMA) polymerization process.

The formulation of mathematical model depends on many parameters. Lasserre (1992) have considered unit holding cost, backlogging cost and set up cost. Matta and Guignard (1994) have considered production cost, inventory cost and changeover cost. Wolsey (1997) have considered production cost, set up cost, recycle cost, changeover cost and inventory storage cost. Zhang and Yan (2005) have considered inventory holding cost, production cost, penalty cost of overproduced and under produced parts, set up cost. Wu and Ierapetritou (2007) have considered raw material cost, inventory cost, backorder cost, operating cost. Gaglioppa et al. (2008) considered to minimise total of production cost, setup cost and inventory holding cost while the constraints are production capacity and availability of processing units. Sung and Maravelias (2008) have considered inventory cost and set up cost. Kopanos et al. (2010) have considered inventory cost, operating cost, fermentation recipe preparation cost, unit utilization cost, product family changeover cost. Kopanos et al. (2011) have considered total inventory, backlog, changeover and operating cost. Xue et al. (2011) have considered unit production cost, inventory carrying, subcontracting, backordering, regular time and overtime cost. Yan et al. (2014) developed mathematical model by considering cost of production, inventory, penalty because of output of shortfall, tardiness and set up.

After identifying the gap in the literature review, a real-life problem of material flow optimisation problem of a soap finishing line is considered. The problem is similar to multistage, multiproduct parallel lines. For the simplification of this problem, the problem of soap finishing line is considered as a flow shop problem. A mathematical model is prepared based on mixed integer non-linear programming for production planning model. The mathematical model is prepared by considering the objective function to minimise the material flow of the multiproduct, multistage problem which consists of processing time, set up time and recycle time. The capacity of the lines and total available time are considered as constraints.

In the next section, the issues of flexible manufacturing system are discussed and proposed mathematical model is presented.

3. Formulation of Mathematical model for production planning problem

In this section a mathematical model is formulated for production planning problem.

In process industries, products are manufactured in various batches. The demand of the products does not remain same due to seasonal change such summer, winter and rainy seasons. To fulfill the demand of the customers in time, the production plans are prepared on the basis of planning periods. The duration of a planning period can be a week, month or years. There are capacity limitations of the equipment on the manufacturing units. The production rate of all the equipment can be different. Due to these issues, the processing time required for all the products on different equipment is different. Hence, for the same product the starting and finishing time can be different on different equipment. Hence, to obtain an optimum production plan is a time consuming and complex work. In production planning problem, the decision variables are large, the search space to obtain an optimum solution is also large. So, due to the complexity of the nature of the problem, it becomes Np-hard.

In the production planning problem, the optimum usage of resources for the transformation of raw materials to the finished product is determined. In this decision stage, the total planning horizon is divided in uniform or non-uniform time periods of week or month. The number of products to be manufactured and demand of all the products is known. The production rate and production capacity are also known. In the planning stage, the objective considered to optimise the material flow of the finishing line and the capacity of the lines is considered as constraint.
The problem addressed in this work is as follows:

In this work, a real-life problem of a soap finishing line is considered. Due to the issues related to confidentiality, the data is slightly modified. This is a multi-product, multistage batch plant produces a set of '*n*' products labeled with the indices i=1, . . . ;,n, where the product i has the known and uniform demand d_i over the planning period. The manufacturing operations are performed on different lines which are represented by the indices l=1, . . . , L. There is a set of m machines labeled with the indices j= 1, . . . ,m. Each line consists of m stages each having one processing unit. All the products use all the processing stages in the same order. A finite long-range time horizon, H_l is also known which is then subdivided into k time periods. The end of each time period corresponds to due dates on which the product demands are to be fulfilled. There is single stamping machine on each line and each have different production rate. The production time, setup time and recycle time are known. The objective of this work is to determine feasible production plan by which the demand of the customers will be satisfied with an optimum material flow. The mathematical model is prepared in the form of mixed integer linear programming.

Index sets are:

$i \in \{1,2,\ldots n\}$	number of products,
$l \in \{1,2,\ldots L\}$	number of lines,
d_i	Total demand of the products,
W_{ilk}	amount of product i produced on line l during time slot k,
H_l	The length of cycle of line l,
T_{lk}	the length of time slot k in line l,
r_{il}	production rate,
C_{il}	capacity of the line l for producing product i
$T_{process_{il}}$	Processing time of product i on line l,
$T_{setup_{il}}$	Setup time of product i on line l,
$T_{recycle_{il}}$	Recycle time of product i on line l,
$T_{total_{il}}$	Total completion time of product i on line l,

The 0-1 decision variables are denoted by y_{il} where y_{il} = 1if product i is processed on line l and zero otherwise. The multi stage, multi-product model is formulated as

1) The processing time of the product is given by:
$$T_{process_{il}} = \frac{d_i}{r_{il}} , \qquad \forall\ i,l \tag{1}$$
2) The setup time is given by:
$$T_{setup_{il}} = \alpha\ T_{process_{il}} \qquad \forall\ i,l \tag{2}$$

3) The recycle time is given by:
$T_{recycle_{il}} = \beta\ T_{process_{il}}$, $\forall$ i,l (3)

4) The total completion time is given by:
$T_{total_{il}} = T_{process_{il}} + T_{setup_{il}} + T_{recycle_{il}}$, $\forall$ i,l (4)

The objective function considered to minimise the total completion time and given by:

$$Min \quad (T_{process_{il}} + \alpha T_{process_{il}} + \beta T_{process_{il}}).\, y_{il} \ , \forall \text{ i=n, } l\text{=L} \quad (5)$$

Constraints:

The amount of products produced on a particular line is less than or equal to the capacity of that line.

$$\Sigma\, W_{il} \leq C_{il} \quad (6)$$

Other variables are:

The length of cycle time of a line is equal to the summation of lengths of all the time slots

$$H_l = \sum_{k=1}^{K} T_{lk} \ , \forall l, k \quad (7)$$

Exactly one product *i* must be assigned to the packaging line *j* in period k

$$\Sigma y_{il} = 1, \ \forall i,l \quad (8)$$

The model is nonlinear due to the quadratic term H_l in constraint (7) (Sahinidis and Grossmann, 1991a; Xue *et al.*, 2011). The solution to the non-linear programming problem is difficult due to large number of continuous variables (Sahinidis and Grossmann, 1991a). Due to this (Stecke, 1983; Sahinidis and Grossmann, 1991a, 1991b; Xue *et al.*, 2011) converted the nonlinear problems to linear by neglecting some constraints such as set up cost, inventory cost, capacity constraint, due dates and demand of the products. This reduces complexity of the problem and the solution obtained will become infeasible in the real time scheduling system.

In the next section, the real-life case study problem is discussed.

4. Case study

In this work, an optimisation of a real-life problem of soap finishing line is considered. The planning period of one week is considered. There are 12 products to be manufactured from 3 soap finishing line. The production rate of all 3 machines for the different products is given in table 1. The weekly demand of all the 12 products is given in table 2. These 12 products can be manufactured from any line. Each finishing line have 1 stamping machine and production rate of every stamping machine is different. Each stamping machine delivers the soaps to two wrapping machine in equal quantity which are running at same speed. The weekly demand of every product is known. The layout of the soap finishing line is shown in figure 2. A brief description of all the stages of soap finishing line is as follows:

In this work, following data is collected:

1. The number and types of products
2. The number of soap finishing lines
3. The products assigned to soap finishing lines
4. Daily recycle time and recycle cost
5. Set up time and set up cost of the machines
6. The scheduling time horizon usually 1 week
7. The processing time and processing cost of each soap finishing line
8. Packaging rate of each product
9. The initial inventory of each product
10. The product demand and due date

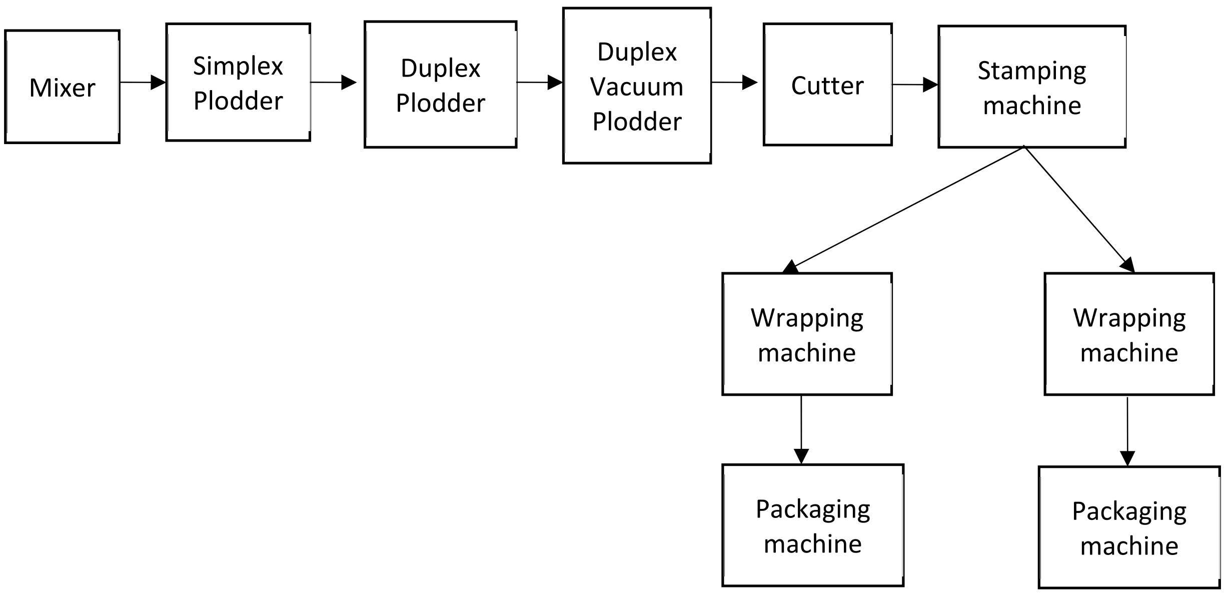


Figure 2. Layout of a soap finishing line

The Production rate, (r_{il}) soaps per minute per line is shown in table 1. The Production rate of line 1 for 45 gm is 480 soaps per minutes, for 75 gm 320 soaps per minutes and for 125 gm 240 soaps per minutes. There are 12 different products of different sizes and colours to be manufactured from 3 lines. The weekly demand of the 12 products is given in table 2. The setup time is assumed to be 30 minutes for each shift of 480 minutes and recycle time 10 minutes for each shift of 480 minutes. So, from the time required to manufacture the required quantity i.e. processing time, the setup time and start up time required for that product are calculated in the fraction of time.

Table 1. Production rate, (r_{il}) soaps per minute per line

	45gm	75gm	125gm
Line#1	480	320	240

Line#2	504	336	252
Line#3	528	352	264

Table 2. Weekly demand (*di*) of products in 10^6 gm

Products (i)	**Colour**	**Size**	**Demand *(di)***
1	Orange	45	36
2	Orange	75	91
3	Orange	125	23
4	Blue	45	15
5	Blue	75	41
6	Blue	125	21
7	White	45	27
8	White	75	67
9	White	125	43
10	Yellow	45	32
11	Yellow	75	47
12	Yellow	125	38

The flexibility of this problem is complex and can be calculated. Let '*i*' be total products to be processed on 'm_j' machines on *l* lines. Therefore, the number of possible solutions can be calculated by (Abazari, Solimanpur and Sattari, 2012):

Number of Possible solutions=

$$\prod_{i=1}^{n}\left\{\left(\prod_{l=1}^{L} m_j\right)+1\right\} \tag{9}$$

$$\prod_{i=1}^{12}\left\{\left(\prod_{l=1}^{3} m_j\right)+1\right\} = (12! \times ((3\times2)+1))$$

$= 3.35\times10^9$ Solutions.

So, there can be 3.35×10^9 possible solutions generated for this problem. To find a global solution is time consuming work. Thus, this problem is complex and Np-hard. Some of the solutions may not be feasible due to constraint of machine availability time. As to determine the optimum solution from all these solutions, it is computationally difficult.

In the next section a brief information about Real Coded Genetic Algorithm (RCGA) is presented.

5. Result and discussion:

In one day, the plant is running in 3 shifts each of 480 minutes. So, the available time of the week is 8640 minutes (=3×6×480). The total completion time of all the products should be less than available time which is given eq. (4). The batch size of the mixer is 500 kg in which the raw material is mixed thoroughly and then dropped in the simplex plodder.

In table 3, comparison between optimum solution used by the industry and proposed methodology is presented. The sequence of products is (i1j1,i1j2,i1j3,i2j1,i2j2,i2j3,….i4j3) means on line 1, product number 6 will be processed first, on line 2, product number 7 will be processed first and on line 3, product number 10 will be processed first. On line 1, after finishing product 6, product 8 will be processed. As per table 2, the product 6 is having blue colour and of size 125 gram whereas, product 8 is having white colour and of size 75 gram. So, there will be a size and colour changeover after finishing product 6 on line 1. The changeover time is calculated by using eq. (28). There is a reduction of material flow time by 136.33 minutes.

Table 3. Optimum solution

Sr. No.	Methodology	Sequence of products	Material flow time (min.)
1	Solution used by industry	1-2-4-5-6-11-12-7-8-10-3-9	8183.57
2	Cplex solver	6-7-10-8-1-4-9-5-2-12-11-3	8087.64

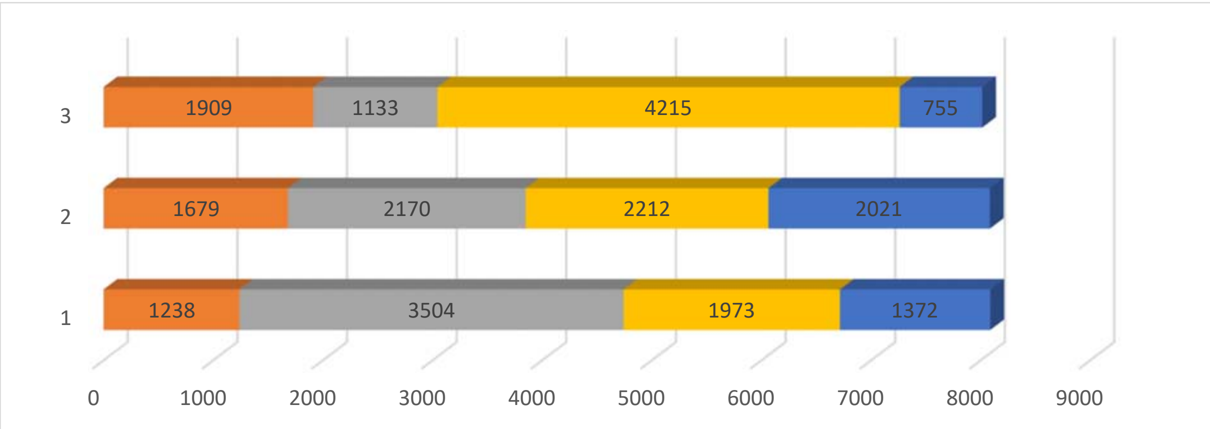


Figure 3. Gantt's chart for optimum solution

The Gantt's chart for the optimum solution given in table 3 is shown in figure 3. The chart shows material flow time in minutes for 3 different lines. The solution convergence graph for RCGA is shown in figure 4.

There are many usefulness of proposed approach to the management. Management can use this integrated approach of production planning and scheduling for preparing the production plan and implementing the same. This approach is more effective and time saving as compared to traditional approach. Even in the case of real time scheduling scenarios such as machine breakdown, less manpower or shortage of the raw material, the solver is useful to find the optimum solution.

Conclusion:

In this work, a real-life problem of optimisation of production planning problem of a soap finishing line is considered. This is a multiproduct, multistage parallel line flowshop problem. For this problem a mathematical model is formulated by considering mixed integer non-linear programming method (MINLP). The production planning period is considered of a week. The demand for the week of all the products are already known. There are 3 finishing lines and from these 3 lines 12 different products are manufactured. The objective function considered is based on minimizing the material flow which consists of total of processing time, setup time and recycle time. For planning problem capacity of the plant is considered as constraint.

References:

Abazari, A. M., Solimanpur, M. and Sattari, H. (2012) 'Optimum loading of machines in a flexible manufacturing system using a mixed-integer linear mathematical programming model and genetic algorithm', *Computers and Industrial Engineering*, 62(2), pp. 469–478.

Bhosale, K. C. and Pawar, P. J. (2018) 'Material flow optimisation of production planning and scheduling problem in flexible manufacturing system by real coded genetic algorithm (RCGA)'. Flex Serv Manuf J.

Chu, Y. *et al.* (2015) 'Integrated planning and scheduling under production uncertainties: Bi-level model formulation and hybrid solution method', *Computers and Chemical Engineering*, 72, pp. 255–272.

Chuang, Y.-C., Chen, C.-T. and Hwang, C. (2016) 'A simple and efficient real-coded genetic algorithm for constrained optimization', *Applied Soft Computing*, 38, pp. 87–105.

Francesco Gaglioppa, Lisa A. Miller, Saif Benjaafar, (2008) Multitask and Multistage Production Planning and Scheduling for Process Industries. Operations Research 56(4), pp.1010-1025.

Georgios M. Kopanos, Luis Puigjaner, and C. T. M. (2011) 'Production Planning and Scheduling of Parallel Continuous Processes with Product Families', *Industrial & Engineering Chemistry Research*, 50(3), pp. 1369–1378.

Herrera, F., Lozano, M. and Verdegay, J. L. (1998) 'Tackling Real-Coded Genetic Algorithms: Operators and Tools for Behavioural Analysis', *Artificial Intelligence Review*, 12(4), pp. 265–319.

Homaifar, a., Qi, C. X. and Lai, S. H. (1994) 'Constrained Optimization Via Genetic Algorithms', *Simulation*, 62(4), pp. 242–253.

Hong-Sen Yan , Qi-Feng Xia , Min-Ru Zhu , Xia-Ling Liu & Zhi-Min Guo (2003) Integrated Production Planning and Scheduling on Automobile Assembly Lines, IIE Transactions, 35:8, 711-725.

Kopanos, G. M., Puigjaner, L. and Georgiadis, M. C. (2010) 'Optimal production scheduling and lot-sizing in dairy plants: The yogurt production line', *Industrial and Engineering Chemistry Research*, 49(2), pp. 701–718.

Lasserre, J. B. (1992) 'An Integrated Model for Job-Shop Planning and Scheduling', *Management Science*, 38(8), pp. 1201–1211.

Maravelias, C. T. and Sung, C. (2009) 'Integration of production planning and scheduling: Overview, challenges and opportunities', *Computers and Chemical Engineering*, 33(12), pp. 1919–1930.

Mcdonald, C. M. and Karimi, I. a (1997) 'Planning and Scheduling of Parallel Semicontinuous Processes . 1 . Production Planning', Ind. Eng. Chem. Res., 36, pp. 2691–2700.

Méndez, C. A. *et al.* (2006) 'State-of-the-art review of optimization methods for short-term scheduling of batch processes', *Computers and Chemical Engineering*, 30(6–7), pp. 913–946.

Mula, J. *et al.* (2006) 'Models for production planning under uncertainty: A review', *International Journal of Production Economics*, 103(1), pp. 271–285.

O. O. Balogun & K. Popplewell (1999) 'Towards the integration of flexible manufacturing system scheduling,' International Journal of Production Research, 37:15, pp. 3399-3428.

Phanden, R. K., Jain, A. and Verma, R. (2011) 'Integration of process planning and scheduling: A state-of-the-art review', *International Journal of Computer Integrated Manufacturing*, 24(6), pp. 517–534.

Pinto, J. M. and Grossmann, I. E. (1998) 'Assignment and sequencing models for the scheduling of process systems', *Annals of Operations Research*, pp. 433–466.

Pinto, J. M., Joly, M. and Moro, L. F. L. (2000) 'Planning and scheduling models for refinery operations', *Computers and Chemical Engineering*, 24(9–10), pp. 2259–2276.

Renato de Matta, Monique Guignard, (1994) Dynamic Production Scheduling for a Process Industry. Operations Research, 42(3), pp. 492-503.

Sahinidis, N. V. and Grossmann, I. E. (1991a) 'MINLP model for cyclic multiproduct scheduling on continuous parallel lines', *Computers and Chemical Engineering*, 15(2), pp. 85–103.

Sahinidis, N. V. and Grossmann, I. E. (1991b) 'Reformulation of multiperiod MILP models for planning and scheduling of chemical processes', *Computers and Chemical Engineering*, 15(4), pp. 255–272.

Shao, X. *et al.* (2009) 'Integration of process planning and scheduling—A modified genetic algorithm-based approach', *Computers & Operations Research*, 36(6), pp. 2082–2096.

Shapiro, J. F. (1993) 'Chapter 8 Mathematical programming models and methods for production planning and scheduling', *Logistics of Production and Inventory*, 4, pp. 371–443.

Shi, H. and You, F. (2015) 'Robust optimisation for integrated planning, scheduling and dynamic optimisation of continuous processes under uncertainty', *Chemical Engineering Transactions*, 45, pp. 859–864.

Stecke, K. E. (1983) 'Formulation and Solution of Nonlinear Integer Production Planning Problems for Flexible Manufacturing Systems', *Management Science*, 29(3), pp. 273–288.

Sung, C. and Maravelias, C. T. (2008) 'A mixed-integer programming formulation for the general capacitated lot-sizing problem', *Computers and Chemical Engineering*, 32(1–2), pp. 244–259.

Vipul Jain, Ignacio E. Grossmann, (2001) Algorithms for Hybrid MILP/CP Models for a Class of Optimization Problems. Informs Journal on Computing, 13(4), pp. 258-276.

Wolsey, L. a. (1997) 'MIP modelling of changeovers in production planning and scheduling problems', *European Journal of Operational Research*, 99(1), pp. 154–165.

Wu, D. and Ierapetritou, M. (2007) 'Hierarchical approach for production planning and scheduling under uncertainty', Chemical Engineering and Processing, 46, pp. 1129–1140.

Xue, G. *et al.* (2011) 'Integrated production planning with sequence-dependent family setup times', *International Journal of Production Economics*, 131(2), pp. 674–681.

Yan, H. and Zhang, X. (2007) 'A Case Study on Integrated Production Planning and Scheduling in a Three-Stage Manufacturing System', IEEE Transactions On Automation Science And Engineering, 4(1), pp. 86–92.

Zhang, X. D. and Yan, H. S. (2005) 'Integrated optimization of production planning and scheduling for a kind of job-shop', *International Journal of Advanced Manufacturing Technology*, 26(7–8), pp. 876–886.