CHEMICAL ENGINEERING TRANSACTIONS

VOL. 70, 2018

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Timothy G. Walmsley, Petar S. Varbanov, Rongxin Su, Jiří J. Klemeš

ISBN 978-88-95608-67-9; **ISSN** 2283-9216

DOI: 10.3303/CET1870177

Task-based Shift Scheduling through Process Integration Technique

Shibani Veeraragavan[a], Wai Mun Chan[a], Irene M.L. Chew[a,*], Dominic C.Y. Foo[b]

[a]School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, 47500 Bandar Sunway, Selangor, Malaysia
[b]Centre of Excellence for Green Technologies, University of Nottingham Malaysia Campus, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia
Irene.Chew@monash.edu

This paper presents a Pinch Analysis-based methodology for general shift scheduling problems with task-based demand. Shift scheduling, which is a subset of staff scheduling is a widely researched field that has recently received more attention because of the great potential to reduce labour costs in organizations by optimizing staff schedules. Although several mathematical approaches such as mixed integer programming and linear programming methods exist in literature and commercial scheduling software are available, the visual nature of pinch analysis would make scheduling easier and more flexible for organizations by enabling them to understand the effects of employee leave, deadline shifts and other schedule changes on the overall minimum outsourcing required. The method proposed in this paper extends previous work on improving shift schedules through pinch analysis, now enabling the targeting of overall minimum outsourcing required for larger groups of employees through a Total Time Pinch Diagram.

1. Introduction

Personnel scheduling, also known as staff scheduling or 'rostering' is the process of creating work schedules for employees in an organization. Although this process has existed for a long time, it has recently received more research attention as industries are aiming to reduce labour costs by optimizing staff schedules (Van den Bergh et al., 2013). Effective scheduling can reduce labour costs by reducing employee 'idle time' as well as overtime or outsourcing.

Scheduling problems are often highly constrained, and the need to accommodate employees' preferences further adds to their complexity. A variety of solution methods can be found in literature, including mathematical programming, heuristic or metaheuristic approaches. According to a review article by Van den Bergh et al. (2013), most solutions to personnel scheduling problems found in the literature use mathematical programming approaches, such as mixed integer programming (MILP), integer programming (IP) and linear programming (LP). These are solved using decomposition methods like column generation (Bard and Purnomo, 2005) and cut generation (Detienne et al., 2009). Several other authors use metaheuristic and heuristic solution methods such as genetic algorithm (Aickelin and Dowsland, 2004), particle swarm optimization (Akjiratikarl et al., 2007), neural network (Hao et al., 2004), ant colony optimization (Gutjahr and Rauner, 2007), etc. Although there are some papers with general solution methods (no particular field of application), most papers have specific fields of application (Van den Bergh et al., 2013). Some of the most common applications include nurse rostering and healthcare (Bard and Purnomo, 2005), transportation (Goel et al., 2012), manufacturing (Bhatnagar et al., 2007) and call centre applications (Alfares, 2007).

The staff scheduling process is commonly classified as proposed by Baker (1976) into shift scheduling, days-off scheduling and tour scheduling. Shift scheduling is the allocation of employees to predefined shifts, while days-off scheduling involves selection of the number of rest days and when they should occur in the planning horizon. Combining both gives rise to the tour scheduling problem (Van den Bergh et al., 2013). Different applications require different types of scheduling; for example, in organizations where working days for employees are already fixed, days-off scheduling would not be required and only shift scheduling is required.

Please cite this article as: Veeraragavan S., Chan W.M., Chew I.M., Foo D.C.Y., 2018, Task-based shift scheduling through process integration technique , Chemical Engineering Transactions, 70, 1057-1062 DOI:10.3303/CET1870177

Ernst et al. (2004) have identified three types of work demand that most applications can be categorized under, i.e. task-based, shift-based and flexible demand. In task-based demand, the demand consists of a list of predefined tasks that must be completed within a given time frame, and the tasks would vary from time to time. In shift-based demand, the number of employees required to be on duty during each shift is predefined. On the other hand, the demand is less predictable in flexible demand problems and may vary according to external factors, such as the number of calls received at a call centre.

In this paper, general shift scheduling problems with task-based demand are approached using Pinch Analysis, in order to obtain the minimal outsourcing target for a group of employees. Pinch analysis is an insight-based approach that was originally developed for heat exchanger network synthesis during the first oil crisis in mid-1970s, and was later extended to other heat recovery systems (Linnhoff et al., 1982). Since the 1990s, pinch analysis has been extended to address various waste minimisation problems such as water recovery (Wang and Smith, 1994) and chilled water network synthesis (Foo et al., 2014). In the past decade, Pinch Analysis has also been extended to address issues such as carbon emissions management (Tan et al., 2017) and various production planning problems in the industry.

Foo et al. (2010) first proposed the graphical tool based on Pinch Analysis to determine the minimum outsourced work time required for individual employees with defined sets of tasks, as well as excess time each employee has after completing his/her tasks. Their work aims to enable employees to effectively schedule personal leave such that their task schedules are not disturbed. They have also explored ways to reduce overall outsourced work time for pairs of employees, by determining the available time slots when employees can assist each other without disturbing their own task schedules. Lim et al. (2013) later extended the graphical pinch analysis tool of Foo et al. (2010) to optimize capacities of manufacturing facilities. In their later works, they also addressed the problem with fixed/variable capacity and variable time problems (Lim et al., 2014). Compared to other staff scheduling methods, Pinch Analysis provides more visual insights with its graphical approach. Since many organizations today still prefer to create staff schedules manually (Rocha et al., 2013), this graphical approach would be more appealing and simpler to use (than other mathematical methods).

While the work by Foo et al. (2010) focuses on enabling employees to optimize their personal schedules, this paper focuses on optimizing an overall schedule for a group of employees in order to achieve an overall minimum outsourcing target. Although a way to reduce outsourcing has been proposed by Foo et al. (2010), the approach is limited to a pair of employees, and does not work well for cases with several employees. Hence, it is the objective of this work to extend the graphical tool for shift scheduling for larger groups of employees.

2. Problem statement

A generalized shift scheduling problem is considered, with the aim to optimize the availability of existing employees in an organization. The work demand is represented by a set of tasks. The planning horizon (time duration for which scheduling must be done) is predefined, and can range from days to weeks, or even months. Each task (Sink) *j* will have a predefined deadline (D_j), as well as work content (W_j, defined in units of time duration). Work content can be defined in two ways depending on the nature of the application: (1) The total amount of time (in the planning horizon) that is available to employees to complete the task; this definition may be useful in cases where the number of employees (and their availability) is fixed and the total available time in the planning horizon is divided between all the tasks; (2) The total amount of time an average employee would take to complete a task; this option would be more useful when the number of employees needed to complete all the tasks is unknown.

Each employee (Source, *i*) will have a predefined work duration, i.e. the number of employees available during each time interval is fixed. It is also assumed that all employees can perform all tasks at the same pace. It is intended to find the overall minimum overtime/outsourcing requirement for the team of employees.

3. Methodology

The procedure to perform targeting for minimum outsourcing requirement for a team of employees is shown in the flowchart in Figure 1. Detailed steps for the targeting procedure are illustrated using the example in the following section.

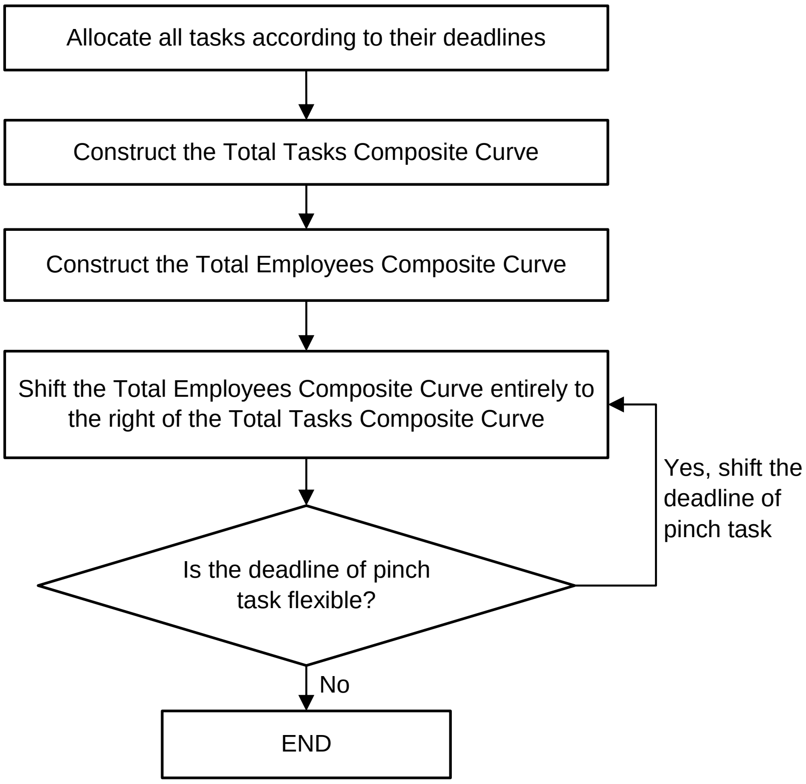

Figure 1: Targeting procedure with Total Time Pinch Diagram

4. Case Study

Consider the following example where four engineers have their own task schedules for a planning horizon of 21 d, i.e. between 10th January (Monday) and 28th January (Friday). The tasks for individual engineers are shown in the form of Tasks Composite Curves in the Time Pinch Diagrams in Figure 2. All four employees are made available throughout the planning horizon but will only work on weekdays. Their availabilities are indicated by the Employees Composite Curves (Figure 2), from where it is also observed that each employee completes 1 d of work content on every working day. Note that the Tasks and Employees Composite Curves have been adopted from Foo et al. (2010); more details on plotting step-like composite curves will be provided later.

From Figure 2, it is observed that all tasks have specific deadlines and associated durations for task completion (work content). Note that the Employees Composite Curves in Figure 2 have been horizontally shifted such that the Tasks and Employees Composite Curves touch at the Pinch point. The Pinch point separates the deficit region (before the Pinch day) and excess region (after the Pinch day) as indicated on Figure 2a. The minimum outsourcing requirement corresponds to the opening on the left of the Time Composite Curves, indicated through the red arrows in each Time Pinch Diagram of Figure 2. Hence, the overall outsourcing requirement is given by the summation of the individual engineers' requirements, i.e. 22 d (= 6+5+8+3 d).

To better utilize the manpower, all sources should be plotted together to form the Total Employees Composite Curve. In other words, each horizontal step on the Total Employees Composite Curve (Figure 3) represents the total work that all four engineers can complete on a workday, which is equal to 4 d. Similarly, all tasks can be collected to form the Total Tasks Composite Curve (Figure 3), where the tasks have been arranged according to their deadlines (Table 1). Note that different tasks that have the same deadlines will be grouped together, and their work contents are added (i.e. $\Sigma_j W_j$). Deadlines have been defined such that all work due on the deadline must be completed before the deadline, not on the deadline interval itself.

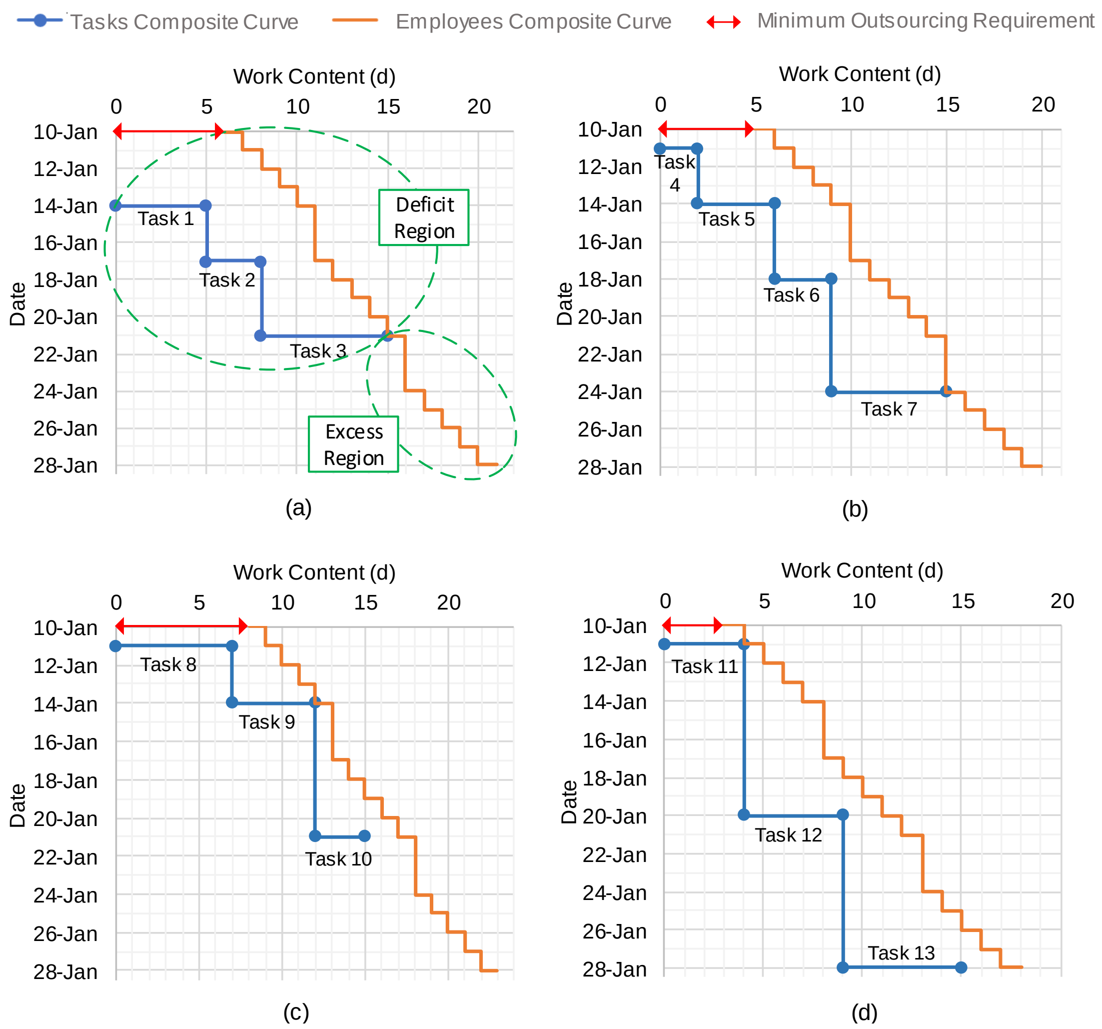

Figure 2: Time Pinch Diagram for: (a) Engineer 1; (b) Engineer 2; (c) Engineer 3; (d) Engineer 4.

Table 1: Total tasks duration according to deadlines

j	Deadline, D_j (date)	Task j	Work Content, $\Sigma_j W_j$ (d)
1	11-Jan	4, 8, 11	13
2	14-Jan	1, 5, 9	14
3	17-Jan	2	3
4	18-Jan	6	3
5	20-Jan	12	5
6	21-Jan	3, 10	10
7	24-Jan	7	6
8	28-Jan	13	6

The Total Employees Composite Curve in Figure 3 is then shifted horizontally so that it does not intersect with the Total Tasks Composite Curve, to form the feasible Total Time Pinch Diagram (Figure 4). From Figure 4, the Pinch day falls on 24th January (Cumulative Work Content = 54 d). It can also be observed that the overall minimum outsourcing requirement (marked using a red arrow) is 14 d, which is less than the original 22 d. This shows that the proposed method provides a lower minimum outsourcing target than the case where there is no interaction among the individual engineers. If deadlines are flexible, it is possible to reduce the minimum outsourcing requirement further by extending the deadline at the Pinch. Figure 5 shows the case where the Pinch deadline has been extended by one day, to 25th January. The minimum outsourcing requirement reduces to 12 d and the new Pinch point falls on 21st January.

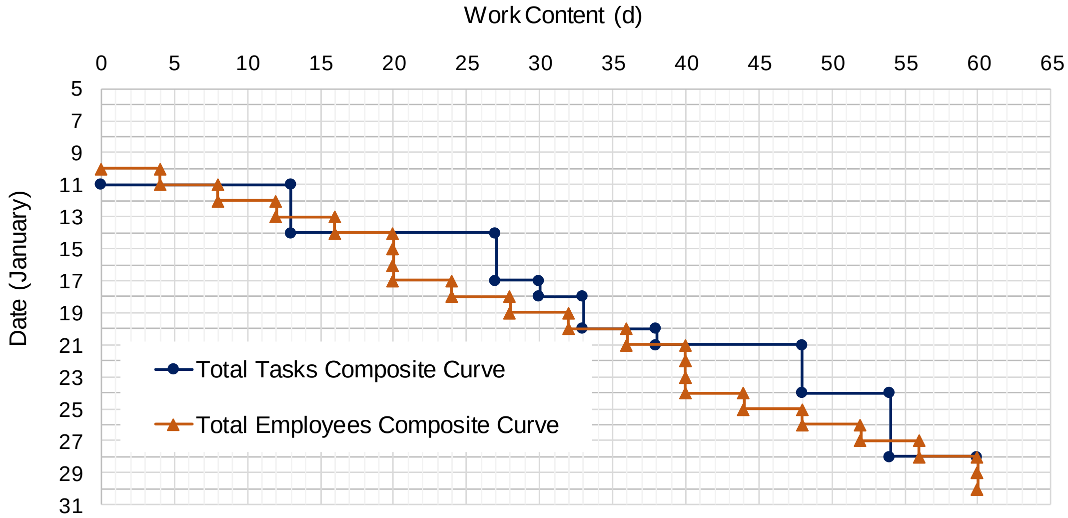

Figure 3: Total Time Pinch Diagram (infeasible)

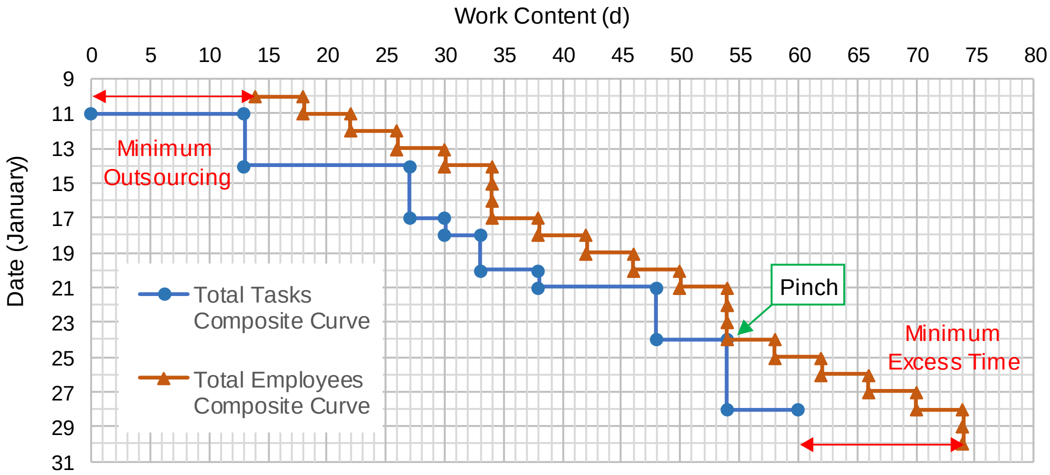

Figure 4: Feasible Total Time Pinch Diagram

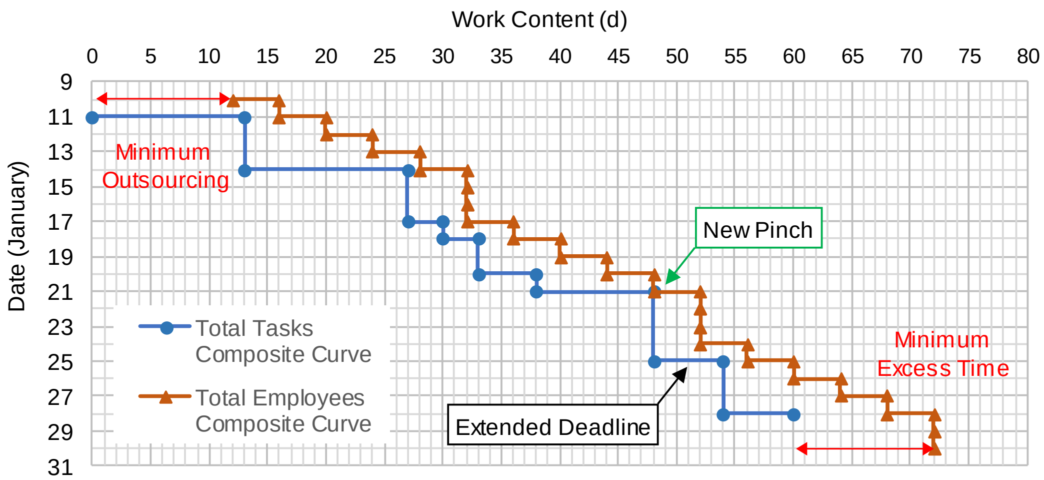

Figure 5: Total Time Pinch Diagram with extended pinch deadline.

5. Conclusion

A Pinch Analysis-based method has been developed to tackle general shift scheduling problems with task-based demand for multiple employees. Time Pinch Diagrams have been used to find the minimum outsourcing target for a group of employees with the same skills, and it has been demonstrated that extending the pinch deadline can reduce this target further; in the above example, the target was reduced from 14 d to 12 d of outsourcing after the pinch deadline was extended. The visual nature of this method can help employers or employees to easily understand the effects of deadline changes, addition or removal of tasks and employee leave on the overall schedule, and easily re-adjust the schedules as well. This method can be further extended to handle groups of employees with different skill sets and different working paces. Besides, future works could also consider the mapping of content hours to labor costs, allowing the targeting of minimum cost of labor in workload allocation using pinch analysis.

References

Aickelin U., Dowsland K.A., 2004, An indirect genetic algorithm for a nurse-scheduling problem, Computers & Operations Research, 31, 761-778.

Akjiratikarl C., Yenradee P., Drake P.R., 2007, PSO-based algorithm for home care worker scheduling in the UK, Computers & Industrial Engineering, 53, 559-583.

Alfares H.K., 2007, Operator staffing and scheduling for an IT-help call centre, European Journal of Industrial Engineering, 1, 414-430.

Baker K.R., 1976, Workforce allocation in cyclical scheduling problems: a survey, Operational Research Quarterly, 27, 155-167.

Bard J.F., Purnomo H.W., 2005, Preference scheduling for nurses using column generation, European Journal of Operational Research, 164, 510-534.

Bhatnagar R., Saddikutti V., Rajgopalan A., 2007, Contingent manpower planning in a high clock speed industry, International Journal of Production Research, 45, 2051-2072.

Detienne B., Peridy L., Pinson E., Rivreau D., 2009, Cut generation for an employee timetabling problem, European Journal of Operational Research, 197, 1178-1184.

Ernst A.T., Jiang H., Krishnamoorthy M., Sier D., 2004, Staff scheduling and rostering: A review of applications, methods and models, European Journal of Operational Research, 153, 3-27.

Foo D.C.Y., Hallale N., Tan R.R., 2010, Optimize shift scheduling using pinch analysis: This technique, already proven in countless heat-integration and waste-minimization operations, can also be applied to human resources management, Chemical Engineering, 117, 48-52.

Foo D.C.Y., Ng D.K.S, Chew I.M.L., Lee J-Y., 2014, A Pinch-Based Approach for the Synthesis of Chilled Water Network, Chemical Engineering Transactions, 39, 1057-1062.

Goel A., Archetti C., Savelsbergh M., 2012, Truck driver scheduling in Australia, Computers & Operations Research, 39, 1122-1132.

Gutjahr W.J., Rauner M.S., 2007, An ACO algorithm for a dynamic regional nurse-scheduling problem in Austria, Computers & Operations Research, 34, 642-666.

Hao G., Lai K.K., Tan M., 2004, A neural network application in personnel scheduling, Annals of Operations Research, 128, 65-90.

Lim J.S.H., Foo D.C.Y., Ng D.K.S., Tan R.R., Aziz R., 2013, Pinch analysis for production planning in manufacturing industries: The two new graphical techniques presented here can help optimize factory capacity and financial resources, Chemical Engineering, 120, 40-45.

Lim J.S.H., Foo D.C.Y., Ng D.K.S., Aziz R.A., Tan R.R., 2014, Graphical Tools for Production Planning in Small Medium Industries (SMIs) based on Pinch Analysis. Journal of Manufacturing Systems, 33, 639–646.

Linnhoff B., Townsend D.W., Boland D., Hewitt G.F., Thomas B.E.A., Guy A.R., Marshall R.H., 1982, Pinch analysis and process integration: A user guide on process integration for the efficient use of energy, Elsevier: Oxford, UK.

Rocha M., Oliveira J., Carravilla F., 2013, Cyclic staff scheduling: Optimization models for some real-life problems, Journal of Scheduling, 16, 231-242.

Tan R.R., Aviso K.B., Foo D.C.Y, 2017, Economy-Wide Carbon Emissions Pinch Analysis, Chemical Engineering Transactions, 61, 913-918.

Van den Bergh J., Beliën J., De Bruecker P., Demeulemeester E., De Boeck L., 2013, Personnel scheduling: A literature review, European Journal of Operational Research, 226, 367-385.

Wang Y.P., Smith R., 1994, Wastewater Minimisation, Chemical Engineering Science, 49, 981-1006.