# Sequencing shop floor operations: a practical approach

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## Abstract

**Purpose** – The work sequence indicated by a production schedule generated by existing scheduling techniques may not necessarily meet the need for efficient sequencing of day-to-day shop floor operations in a dynamic job shop environment. The purpose of this paper is to present a new practical approach to efficiently sequencing day-to-day shop floor operations of a job shop.

**Design/methodology/approach** – A color coding and priority system is introduced to identify production jobs that are to be processed at work centers which have a work sequence preference for performing various jobs. Based on a realistic production schedule, a three-phase sequencing method is developed to create a truly feasible shop schedule, with the most efficient work sequence possible.

**Findings** – Specific features of the approach are presented and illustrated with a numerical example. It enables production jobs to be run in the best possible way at individual work centers. Various options of implementing the approach in practical applications are discussed.

**Research limitations/implications** – The approach serves as an enhanced supplement to a job shop operations scheduling system for efficient sequencing of shop floor operations. It is to be implemented at the shop floor level.

**Practical implications** – The approach can be implemented as a real-time computer integrated shop dispatching system to ensure an efficient work sequence for shop floor operations of job shops in actual industrial settings.

**Originality/value** – The paper addresses the need for effectively coordinating production jobs of varying routings on the shop floor, which cannot be met by existing scheduling techniques or shop dispatching practice. It provides manufacturing practitioners with a structured approach for managing shop floor operations.

**Keywords** Sequential production, Process planning, Shopfloor, Despatch, Job shop

**Paper type** Research paper

## Introduction

In a job shop of process-oriented layout, a work center is designed to perform a particular operation activity, and is capable of processing products (jobs) with a wide variety of specifications. The manufacture of products in such a job shop is usually represented by production jobs (work orders), each of which consists of a number of operations to be processed at the corresponding work centers in varying sequences. Production jobs are scheduled by an operations scheduling system to give the schedule start and finish times of each operation at the corresponding work center, in which the sequence for processing various operations (jobs) on the specified machines is indicated. A shop schedule (dispatch list) by work center and operation is prepared accordingly to show the work to be completed at each work center on a daily or shift-by-shift basis. This task of shop scheduling or dispatching, often taking into account the current production status, is the most common component of MRP (material requirements planning)/MRPII (manufacturing resource planning) systems

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(Baudin, 1990; Landvater and Gray, 1989; Yeh, 1997a). Only efficient execution of the shop schedule at each work center can ensure completion of production jobs on time.

Depending upon the operational characteristics of a work center, several factors may cause the work center itself to have its work sequence preference for processing various jobs. Among the more common are: physical efficiency of the production facility itself, e.g. furnace temperature from low to high, coating shades from light to dark, coating thickness from thin to thick, etc.; different setup or tooling times required for processing various jobs in different sequences, i.e. sequence dependent setup times; and common tooling or materials requirements. The work sequence indicated by a production schedule or shop schedule should ideally suit the efficient operation of individual work centers. However, existing scheduling techniques may not handle this practical sequencing problem adequately on the shop floor.

Scheduling research on the problem of sequence dependent setup times (Allahverdi *et al.*, 1999; Brucker and Thiele, 1996; Farn and Muhlemann, 1979; Missbauer, 1997; O'Grady and Harrison, 1988; White and Wilson, 1977) reflects a typical need for efficient shop floor operations. However, the problem is NP-hard (Karp, 1972) and is mainly applied to a single-machine shop (Allahverdi *et al.*, 1999; Haase and Kimms, 2000) or a flow shop (Chen and Chyu, 2003) environment. In actual job shop settings, the meeting of due dates is often more important than minimizing total setup times (Panwalkar *et al.*, 1973). Scheduling research has suggested that heuristics provide the only viable approach for scheduling job shops of practical size. In order to generate a realistic, detailed production schedule, an operations scheduling system using operation-oriented heuristics (i.e. dispatching rules) (Blackstone *et al.*, 1982; Hax and Candea, 1984; Panwalkar *et al.*, 1973; Rodammer and White, 1988) or job-oriented heuristics (Baker, 1998; Hastings and Yeh, 1990; Walker and Woolven, 1991; Yeh, 2000) is required to schedule production jobs to actual production capacity. No heuristic method performs consistently better than the others for meeting due dates (Baker, 1984) or minimizing total setup times (Allahverdi *et al.*, 1999) in a general job shop environment.

In practice, unexpected daily variations in shop floor operations make any attempt to generate a shop schedule too far ahead unrealistic (Kochhar, 1979). All of these seem to suggest that the efficient sequencing problem of job shop operations would be best handled at the operational (shop floor) level rather than at the planning/scheduling level. In other words, the efficient sequencing for jobs to be carried out at the corresponding work centers can be best realized by shop schedules (dispatch lists), and not necessarily by production schedules generated by an operations scheduling system at a higher level.

A current practice on the shop floor is that, based on the production schedule and the current production status, the foremen or dispatchers can use their intuition and knowledge to combine dispatched jobs with similar operation requirements, for achieving an efficient work sequence (Kochhar, 1979). However, without considering the production schedule as a whole, the dispatcher's manipulation at one work center cannot take into account jobs coming to the work center from the preceding work centers and may affect the work sequence at subsequent work centers.

Clearly, a structural approach is required to: effectively coordinate production jobs of varying routings performed at the corresponding work centers for efficient shop floor operations; and reduce the dependence on key personnel. In addition, the approach requires being implemented as a real-time system to reflect the timely need of shop floor operations. To address these needs, this paper presents a practical approach to sequencing production jobs efficiently on a shop schedule of job shops, which can be easily incorporated into a computer integrated manufacturing system. The approach enables production jobs to be run in the best possible way at work centers which have a given work sequence preference. The approach is based on a color coding system, designed to facilitate the sequencing of production jobs at individual work centers, and to allow meaningful communication within and between work centers on the shop floor.

## The color coding system: work sequence preference of work centers

A work center that has a work sequence preference for performing various jobs is called a "color work center." Each operation of production jobs to be processed by a color work center is given a special operation code and priority value, which are referred to as "color code" and "color sequence" respectively. In a color work center, a setup may be required if the color code of the operation to be processed differs from that of the previously processed operation.

For easy distinction and assignment of color codes within a color work center, all the operation tasks required for processing varying jobs can be classified based on two factors. The first factor is related to those jobs that have a work sequence preference in terms of operation parameters themselves, such as operation tools, setup requirements, material requirements, operation duration, item value, etc. Different series of color codes are applied to this class, such as BLUE, GREEN, and RED. The second factor is concerned with those jobs that cause physical preference in terms of the operation activity itself. For example, the work sequence preference for a cutting operation is from a small size to a large size, or the work sequence preference for coating of the same color is from thin to thick. An identical color with different shades or number codes is used to indicate this preferred technical sequence of an operation activity, such as BLUE1, BLUE2, and BLUE3.

Table I gives a simple example of color coding for work center "Coating," which performs the task of coating glass with coating materials of different colors. SKY 10, SILVER 8, etc. represent metallic coatings of different colors.

The color sequence used here is independent of the job priority (or the dispatching rule) used by an operations scheduling system for achieving an overall scheduling objective, such as meeting the due date. The job priority is used by an operations scheduling system to generate a realistic production schedule. Based on the production schedule, the color sequence is used to yield an efficient work sequence for the daily shop schedule of each color work center, which is referred to as a "color schedule." This is done by sorting the production operations scheduled to start within a specified time

| Color code | Color sequence | Color description |
|---|---|---|
| BLUE1 | 11 | Coating material – SKY 10 |
| BLUE2 | 12 | Coating material – SKY 20 |
| RED1 | 21 | Coating material – SILVER 8 |
| RED2 | 22 | Coating material – SILVER 14 |
| RED3 | 23 | Coating material – SILVER 20 |

**Table I.** Color coding of work center "Coating" bucket at color work centers into their color sequence order. However, the color schedule may not necessarily be feasible, when two or more operations of a production job are involved. In other words, the operation precedence constraints of a production job may not be met by the new schedule times given by the rearrangement of operations at color work centers. This is because the sorting by color sequence for the operations processed at a color work center does not consider the operations of the same job processed at other work centers which are scheduled to start within the same time bucket. To ensure that a truly feasible color schedule is always obtained, an adjusting procedure is needed whenever infeasible results occur. As such, an effective color sequencing method is developed to generate a feasible and efficient color schedule.

## The color sequencing method

The color sequencing method involves the following three phases.

### *Phase 1: creation of a feasible shop schedule*

Based on a realistic production schedule generated by an operations scheduling system (e.g. using dispatching rules), an initial feasible shop schedule for each work center is created by sorting production operations scheduled to start within a specified time bucket into their schedule start time order. The time bucket specified is meant to represent the best working cycle of shop floor operations, e.g. one day.

### *Phase 2: generation of an efficient color schedule*

The production operations (jobs) on the shop schedule of each color work center created at phase 1 are sorted by their color sequence to obtain a color schedule with an efficient work sequence. To make the adjusting procedure at phase 3 (if required) efficient and effective, two measures are taken:

(1) Assign a new schedule time for each operation to be processed according to the new work sequence in the color schedule.

(2) Assign a "color block" to correspond with the new schedule start time and finish time of each set of color-grouped operations. The color-grouped operations are those which have the same color sequence. If the color schedule needs to be adjusted to make it feasible, it is carried out first within the color blocks in order to maintain the efficiency of the work sequence in the color schedule.

### *Phase 3: checking and adjusting for a feasible color schedule*

The purpose of this phase is to ensure that the color schedule is feasible. Jobs which have only one operation involved are obviously feasible, and they can be flexibly reassigned any schedule time within the specified time bucket in the color schedule. Therefore, the checking is only applied to jobs involving two or more operations. Jobs are examined one by one in their priority order. If a job is feasible, then the current schedule times of its operations are fixed and cannot be altered by subsequent adjustments. If a job is found infeasible, the following adjusting steps are carried out:

- *Step 1.* Deschedule the conflicting operations of the job.
- *Step 2.* Reschedule the operations within the color blocks of the corresponding sets of color-grouped operations.

- *Step 3*. If the job is feasible after rescheduling, proceed to step 4. Otherwise proceed to step 6.
- *Step 4*. New schedule times of the operations are fixed and cannot be altered.
- *Step 5*. Deschedule the other operations in the color blocks at step 2 and reschedule them one by one in sequence. The adjustment for the job is completed. The efficient work sequence generated at phase 2 is not affected by the adjustment of steps 2-5.
- *Step 6*. Reschedule the first of conflicting operations by assigning the earliest unused time slot left available at the corresponding work center, that is, loading it onto the corresponding machines as early as possible. Early loading of the preceding operation may avoid the subsequent operations of the job being delayed.
- *Step 7*. Reschedule the next operation involved by the same way as step 6 and with the restriction of the schedule finish time of its preceding operation. This step is repeated until all the involved operations of the job have been adjusted.
- *Step 8*. New schedule times of the operations of the job rescheduled are fixed and cannot be altered.
- *Step 9*. Deschedule the operations at the relevant work centers, which have not been fixed previously, and reschedule them one by one according to their color sequence. The adjustment for the job is complete.

The efficient work sequence generated at phase 2 may be affected to some extent by the adjustment of steps 6-9.

The procedure is repeated until all the jobs involved have been checked. If the work sequence of a color work center has been adjusted by steps 6-9, an additional step is carried out within the work center for improvement. Operations are examined one by one in their current sequence order to move backwards or forwards to directly follow or precede the closest operation of the same color sequence if the operation precedence constraints can still be met. As a result, a truly feasible color schedule with the most efficient work sequence possible is obtained. At worst, the resulting feasible color schedule will be that initially created in the first phase.

The above procedure for rescheduling (or adjusting the schedule time of) operations forwards or backwards can be carried out by a machine loading algorithm. An efficient algorithm for forward and backward loading of individual operations onto capacity constrained parallel machines is presented by Yeh (1997b).

## Example

In this section, an example is used to illustrate how the color sequencing method works. Three work centers (A, B, and C) are involved and each has only one machine available for eight hours in a specified time bucket of one day. Work centers A and B have a work sequence preference and their color coding is given in Table II. Operations processed at work centers A and B require a setup time of 0.1 hour if their previously processed operation at the corresponding work center has a different color code. Work center C has no work sequence preference and no setup time is required for processing any operation.

A total of 11 jobs, numbered from 1 to 11 in order of priority, have at least one operation being scheduled to start on day 1, for which color sequencing with a one-day time bucket is to be applied. Each job has three operations which need to be processed at work centers A, B and C in sequence, except that jobs 6 and 9 have only two operations which require being processed at work centers A and C respectively. Each operation is labeled by its job number and the corresponding work center to be visited. All operations involved are normal with no transport time. All operations scheduled to start and finish on day 1 are given in Table III. Other operations of the jobs involved are not given in Table III, because they are scheduled to start and finish before or after day 1, thus not included in the current run of color sequencing.

Figure 1(a) shows the result of phase 1 of color sequencing, which is the initial feasible shop schedule. The solid bar in front of an operation indicates the setup time required in the schedule. The shaded bar indicates a gap (i.e. slack time) in the schedule, resulting from the operation precedence constraints. In phase 2 of color sequencing, operations at work centers A and B in Figure 1(a) are sorted into their color sequence given in Table II. This sorting results in the efficient color schedule shown as in Figure 1(b). Operations at a non-color work center (e.g. work center C) are regarded

**Table II.**
Color coding of color work centers in the example

| Color code | Color sequence |
|---|---|
| *Work center A* | |
| BLUE | 11 |
| BROWN | 21 |
| *Work center B* | |
| GREEN | 11 |
| RED | 21 |
| YELLOW | 31 |

**Table III.**
Operations involved in the example

| Job | Priority | Operation | Setup time (hour) | Duration (hour) | Work center | Color code |
|---|---|---|---|---|---|---|
| 1 | 1 | 1C | | 2.0 | C | |
| 2 | 2 | 2C | | 2.0 | C | |
| 3 | 3 | 3B | 0.1 | 0.9 | B | YELLOW |
| | | 3C | | 2.0 | C | |
| 4 | 4 | 4B | 0.1 | 0.9 | B | RED |
| | | 4C | | 1.0 | C | |
| 5 | 5 | 5B | 0.1 | 1.9 | B | GREEN |
| | | 5C | | 1.0 | C | |
| 6 | 6 | 6A | 0.1 | 0.9 | A | BROWN |
| 7 | 7 | 7A | 0.1 | 0.9 | A | BLUE |
| | | 7B | 0.1 | 0.9 | B | YELLOW |
| 8 | 8 | 8A | 0.1 | 1.9 | A | BROWN |
| | | 8B | 0.1 | 1.9 | B | YELLOW |
| 9 | 9 | 9A | 0.1 | 1.9 | A | BLUE |
| 10 | 10 | 10A | 0.1 | 0.9 | A | BROWN |
| | | 10B | 0.1 | 0.9 | B | GREEN |
| 11 | 11 | 11A | 0.1 | 0.9 | A | BLUE |

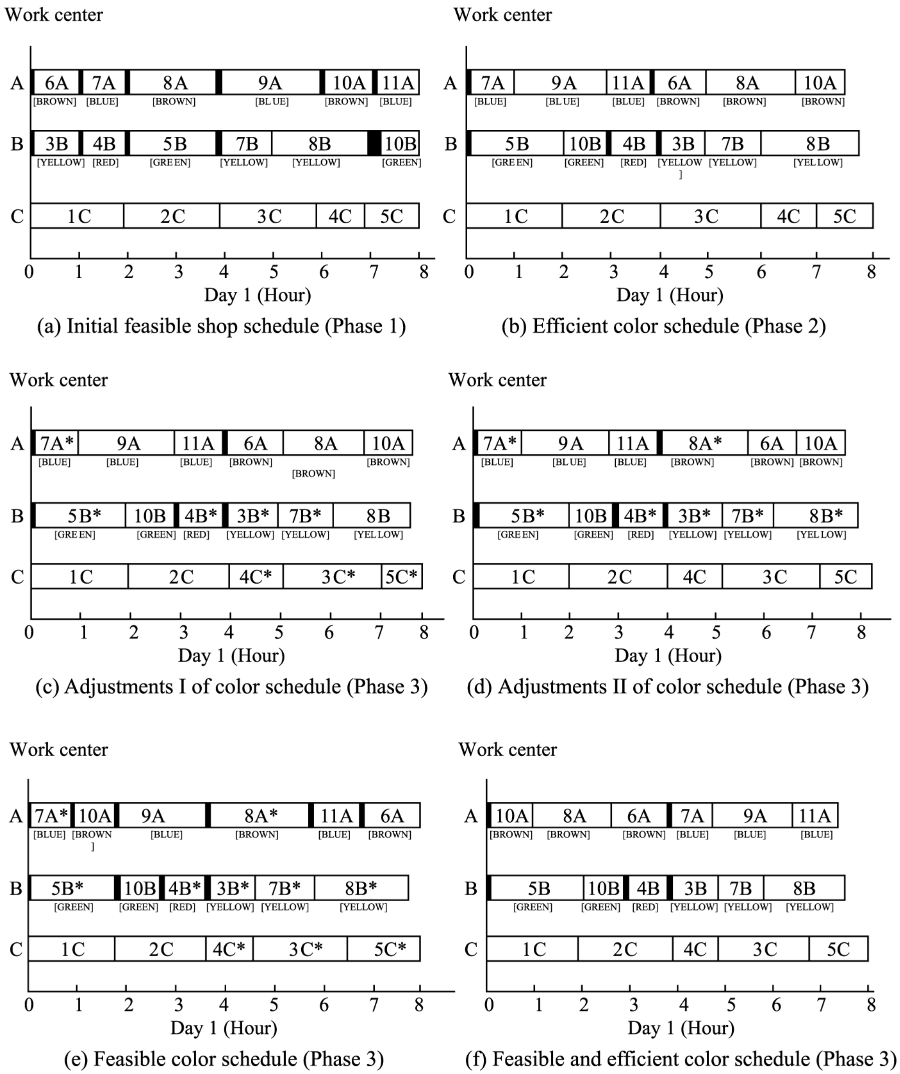


**Figure 1.**
Three phases of color sequencing

as having the same color sequence and treated as a set of color-grouped operations. In phase 3, jobs 3, 4, 5, 7, 8 and 10 are examined in sequence because they have two operations involved.

In Figure 1(b), job 3 is infeasible as its operation precedence constraints are not met. The conflicting operations (3B and 3C) of job 3 are adjusted by steps 1-5 within the color block of [1C, 2C, 3C, 4C, 5C]. This results in an exchange of the schedule time between operations 3C and 4C. After adjustment, the feasible schedule times of operations 3B and 3C are fixed. Jobs 4, 5 and 7 are feasible and their schedule times are fixed. Figure 1(c) shows the result, in which adjusted or examined schedule times are marked with an "*." Job 8 is infeasible and its conflicting operations (8A and 8B) are adjusted by steps 1-5 within the color block of [6A, 8A, 10A]. Figure 1(d) shows the result of adjustment.

Job 10 in Figure 1(d) is infeasible. To make it feasible, operations 10A and 10B are adjusted by steps 6-8, and operations 9A, 11A and 6A are subsequently adjusted by step 9. As a result of these adjustments, a feasible color schedule is obtained, as shown in Figure 1(e). Since the work sequence of work center A has been altered by steps 6-9 of phase 3 for adjusting job 10, operations at work center A are further examined for improvement. Operations 8A and 6A are thus moved forwards to directly follow operation 10A as they are of the same color sequence. Operation 7A is moved backwards to directly precede operation 9A of the same color sequence. The resulting feasible and efficient color schedule is shown in Figure 1(f). At work center A, the work sequence is the best one possible, given the operation precedence constraints. The work sequence at work center B is the most efficient one. The operations to be processed at work centers A and B will be completed earlier due to the reduction of setup times (from six to two setups at work center A, and from five to three setups at work center B).

## Implementation and discussion

In color sequencing, the adjustments for a feasible color schedule at phase 3 may affect the efficiency of the work sequence at color work centers. In practice, however, the effectiveness of color sequencing will most likely be maintained, provided that: only a few work centers have the work sequence preference; color work centers have only a few color codes; there are some unused gaps in the schedule; or the time bucket of color sequencing is short, e.g. one or two days. This conclusion is based on the observation that we had, when the approach presented was incorporated into a computer integrated manufacturing system (Hastings and Yeh, 1990) and implemented in the production of building glass products in a make-to-order job shop.

In this practical application, six out of 17 work centers were color work centers, with the number of color codes ranging from five to eight. Within the specified time bucket of one day, on average 20 to 30 jobs/operations of various operation parameters were processed at each work center, and gaps in the schedule always existed. There was clearly a need to sequence these jobs to meet the specific work sequence preference of color work centers. With the color sequencing method, a feasible and efficient color schedule could be generated in a short amount of computer time, normally within minutes, as the required amount of data processing was not great. This allowed re-sequencing to occur several times a day when needed, which was sufficient to keep the shop schedule efficient and up-to-date for accommodating unexpected operation variations on the shop floor. As a result, the jobs on the shop schedule were generally completed on time, mainly due to the reduction of setup times at color work centers by the color sequencing method.

The color sequencing method presented above is in response to situations where the completion of jobs on time is more important than the work sequence preference of color work centers, if both cannot be met simultaneously. Under certain circumstances, the work sequence preference of a color work center may have to be maintained. In this case, instead of applying phase 3 of color sequencing, overtime work may be needed or some jobs may expect delays when conflicting operations occur. The reduction of setup times resulting from color sequencing would help improve the conflicting situation.

In situations where the subsequent operations of the same job cannot be processed within the specified time bucket due to the nature of work centers or jobs, phase 3 of color sequencing is not required. As such, the color schedule generated at phase 2 is always feasible. This is also the case for situations where the operations of a job to be processed at color work centers are restricted to one operation within the specified time bucket. This operation restriction may lead to later completion of some jobs. In some cases, this seems acceptable to some shops. At this point, it should be noted that the implication of possible "later completion" of a job here is referred only to the comparison between the schedule finish times given by an operations scheduling system with and without the operation restriction respectively. As such, the due date of the job may still be met.

The color sequencing approach presented in this paper serves as an enhanced supplement to a job shop operations scheduling system for efficient sequencing of shop floor operations. It is to be implemented at the shop floor level. The efficient sequencing problem of shop floor operations may be addressed at the planning level. One approach to planning for efficient operations is group technology (GT), which identifies and groups similar products in terms of design and manufacturing to form product families and manufacturing cells (Burbidge, 1979; Groove, 1980; dos Santos and de Araujo, 2003). The efficient organization by GT requires that the production environment be changed from a process-oriented layout to a product-based or cellular-oriented layout, which may be difficult to achieve for some job shops. Although GT can be regarded as a means of improving productivity, its successful implementation requires special consideration to a wide variety of features within a particular production environment (Bauer *et al.* 1991). In addition, it is difficult to create practicable groupings, particularly for job shops of high product varieties and low volumes. As such, a process-oriented layout may still be the best option, if improvements in shop floor performance can be pursued (Hendry, 1998). This may be evidenced by the fact that the majority of the job shops in practice have process-oriented layouts, as opposed to the cellular-oriented or continuous flow layouts (Wisner and Siferd, 1995).

Without a significant change to the production environment, an alternative to GT for grouping products is concerned with the planning of production jobs for making products on a customer order. With an integrated bill of material and routing data structure, products with the same job routing and similar operation parameters can be scheduled and manufactured under one job rather than several jobs (Yeh, 1995). As a result, common operation activities required will always be scheduled to process together, thus facilitating the sequencing of shop floor operations. This special planning feature for grouping products on a customer order can be used as a higher-level input to the color sequencing approach.

## Conclusion

The work sequence indicated by a production schedule generated by existing scheduling techniques for satisfying an overall scheduling objective may not meet the need for efficient sequencing of day-to-day shop floor operations at individual work centers in a dynamic job shop environment. A practical approach based on a color coding and priority system has been presented to ensure an efficient execution of production operations on the shop floor. To generate a truly feasible shop schedule with the best possible efficient work sequence within a specified time bucket, a color sequencing method has been developed. The method incorporates special measures to make the sequencing procedure efficient and effective. In practical applications, the approach can be implemented as a shop dispatching system to ensure an efficient work sequence for shop floor operations in actual industrial settings. It can be used alone or as an enhanced extension to an operations scheduling system. With its simplicity in both concept and computation, the approach can be readily incorporated into a computer integrated job shop manufacturing system.

## References


Allahverdi, A., Gupta, J.N.D. and Aldowaisan, T. (1999), "A review of scheduling research involving setup considerations", *Omega*, Vol. 27 No. 2, pp. 219-39.

Baker, A.D. (1998), "A survey of factory control algorithms that can be implemented in a multi-agent heterarchy: dispatching, scheduling, and pull", *Journal of Manufacturing Systems*, Vol. 17 No. 4, pp. 297-320.

Baker, K.R. (1984), "Sequencing rules and due-date assignments in a job shop", *Management Science*, Vol. 30 No. 9, pp. 1092-104.

Baudin, M. (1990), *Manufacturing Systems Analysis with Application to Production Scheduling*, Prentice-Hall, Englewood Cliffs, NJ.

Bauer, A., Bowden, R., Browne, J., Duggan, J. and Lyons, G. (1991), *Shop Floor Control Systems*, Chapman & Hall, London.

Blackstone, J.H., Phillips, D.T. and Hogg, G.L. (1982), "A state-of-the-art survey of dispatching rules for manufacturing job shop operations", *International Journal of Production Research*, Vol. 20 No. 1, pp. 27-45.

Brucker, P. and Thiele, O. (1996), "A branch & bound method for the general-shop problem with sequence dependent setup-times", *OR Spektrum*, Vol. 18, pp. 145-61.

Burbidge, J.L. (1979), *Group Technology in the Engineering Industry*, Heinemann, London.

Chen, W.-S. and Chyu, C.-C. (2003), "A minimum setup strategy for sequencing PCBs with multi-slot feeders", *Integrated Manufacturing Systems*, Vol. 14 No. 5, pp. 255-67.

dos Santos, N.R. and de Araujo, L.O. (2003), "Computational system for group technology – PFA case study", *Integrated Manufacturing Systems*, Vol. 14 No. 2, pp. 138-52.

Farn, C.-K. and Muhlemann, A.P. (1979), "The dynamic aspects of a production scheduling problem", *International Journal of Production Research*, Vol. 27 No. 1, pp. 15-21.

Groove, W.R. (1980), *Automation, Production Systems, and Computer Aided Manufacturing*, Prentice-Hall, Englewood Cliffs, NJ.

Haase, K. and Kimms, A. (2000), "Lot sizing and scheduling with sequence-dependent setup costs and times and efficient rescheduling opportunities", *International Journal of Production Economics*, Vol. 66, pp. 159-69.

Hastings, N.A.J. and Yeh, C.-H. (1990), "Job oriented production scheduling", *European Journal of Operational Research*, Vol. 47 No. 1, pp. 35-48.

Hax, A.C. and Candea, D. (1984), *Production and Inventory Management*, Prentice-Hall, Englewood Cliffs, NJ.

Hendry, L.C. (1998), "Applying world class manufacturing to make-to-order companies: problems and solutions", *International Journal of Operations & Production Management*, Vol. 18 No. 11, pp. 1086-100.

Karp, R.M. (1972), "Reducibility among combinatorial problems", in Miller, R.E. and Thatcher, J.W. (Eds), *Complexity of Computer Computations*, Plenum Press, New York, NY, pp. 85-104.

Kochhar, A.K. (1979), *Development of Computer-Based Production Systems*, Edward Arnold, London.

Landvater, D.V. and Gray, C.D. (1989), *MRPII Standard System*, Oliver Wight, Essex Junction, VT.

Missbauer, H. (1997), "Order release and sequence-dependent setup times", *International Journal of Production Economics*, Vol. 49 No. 2, pp. 131-43.

O'Grady, P.J. and Harrison, C. (1988), "Search based job scheduling and sequencing with setup times", *Omega*, Vol. 16 No. 6, pp. 547-52.

Panwalkar, S.S., Dudek, R.A. and Smith, M.L. (1973), "Sequencing research and the industrial scheduling problem", in Elmaghraby, S.E. (Ed.), *Symposium on the Theory of Scheduling and its Applications*, Springer-Verlag, Berlin, pp. 29-38.

Rodammer, F.A. and White, K.P. (1988), "A recent survey of production scheduling", *IEEE Transactions on Systems, Man, and Cybernetics*, Vol. 18, pp. 841-51.

Walker, L.K. and Woolven, J.D. (1991), "Development and use of a visual interactive planning board within Alcan Aluminium", *European Journal of Operational Research*, Vol. 54, pp. 35-48.

White, C.H. and Wilson, R.C. (1977), "Sequence dependent setup times and job sequencing", *International Journal of Production Research*, Vol. 15 No. 2, pp. 191-202.

Wisner, J.D. and Siferd, S.P. (1995), "A survey of US manufacturing practices in make-to-order machine shops", *Production and Inventory Management Journal*, Vol. 36 No. 1, pp. 1-7.

Yeh, C.-H. (1995), "Production data modelling: an integrated approach", *International Journal of Operations & Production Management*, Vol. 15 No. 8, pp. 52-62.

Yeh, C.-H. (1997a), "Schedule based production", *International Journal of Production Economics*, Vol. 51, pp. 235-42.

Yeh, C.-H. (1997b), "A fast finite loading algorithm for job oriented scheduling", *Computers and Operations Research*, Vol. 24 No. 2, pp. 193-8.

Yeh, C.-H. (2000), "A customer-focused planning approach to make-to-order production", *Industrial Management & Data Systems*, Vol. 100 No. 4, pp. 180-7.

## Further reading

Newman, W.R. and Maffei, M.J. (1999), "Managing the job shop: simulating the effects of flexibility, order release mechanisms and sequencing rules", *Integrated Manufacturing Systems*, Vol. 10 No. 5, pp. 266-75.

Panwalkar, S.S. and Iskander, W. (1977), "A survey of scheduling rules", *Operations Research*, Vol. 25 No. 1, pp. 45-61.