What is really happening at the shop floor, and why do scheduling techniques not work?

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Paul P.M. Stoop
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Graduate School of Industrial Engineering and Management Science
Eindhoven University of Technology
P.O.Box 513, Paviljoen F15
NL-5600 MB Eindhoven
The Netherlands
Phone: +31.40.474443

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What is Really Happening at the Shop Floor, and Why Do Scheduling Techniques Not Work?

PAUL P.M. STOOP
VINCENT C.S. WIERS

Eindhoven University of Technology
Graduate School of Industrial Engineering and Management Science
P.O.Box 513, 5600 MB, Eindhoven, The Netherlands

Abstract:
In many production departments and especially in job-shops, large deviations are found between scheduled production, that usually is based on a specific theoretically based scheduling technique, and the actual shop floor production. In the article we will explain that this gap is not only caused by everyday disturbances, but also by human factors and the structure of production control. The meaningfulness of the scheduling function in complex production departments will be discussed.

1. Introduction

Production scheduling is an essential and intangible factor of the logistical performance of production organisations. Much research has been carried out in production scheduling. However, there still seems to be a large gap between scheduling theory and practice [King, 1976; Graves, 1981; McKay et al., 1988; Rodammer and White, 1988; Buxey, 1989]. Although many techniques exist for generating production schedules (a review is given in Workman et al., 1994), in many companies these schedules are largely not fulfilled at the shop floor, especially in complex job-shops.

In this paper we will try to clarify the reasons and consequences of the gap between production scheduling and shop floor practice from a number of perspectives. In this paper, we will focus on job-shop like production departments. The following comment must be made here. Typical planning, scheduling and sequencing functions are fulfilled in practice in different ways. Therefore, the statements in this paper will not be equally applicable to each organisation.

The logistic performance of production departments is usually characterised by measures directed at time (e.g., average order flow time, delivery reliability) and quantities (e.g., average throughput). The performance of production departments is supposed to be determined by production scheduling. However, there are many problems that hamper the straightforward execution of production schedules. Therefore, although many techniques exist for generating production schedules, scheduling still is a typical human task in most companies.

Many deviations between the planned and the actual production schedules will be caused by well-known disturbances. However, we feel that the gap between production scheduling and shop floor practice has a much deeper source. In this paper we will discuss these problems from the following perspectives: scheduling theory, the cognitive abilities of humans, and the structure of production control.

The structure of this paper is as follows: In Section 2 of this paper we will give a definition of scheduling and how it relates to planning and sequencing. In Section 3, we will discuss common disturbances that hinder the execution of scheduled production, and their impact on estimations of shop floor performance. In Section 4 a brief overview is given of existing shop floor models and scheduling techniques. In Section 5 a description is given of human factors in production scheduling. In Section 6 we will discuss the structure of production control and the problems this imposes on production scheduling. In our discussion in Section 7 the impact of the foregoing problems in scheduling will be discussed.

1
2. Planning, Scheduling, and Sequencing

In literature often a distinction is made between planning, scheduling, and sequencing. However, clear definitions for each of these functions can hardly be found. This especially holds for the distinction between scheduling and sequencing. In this section, planning, scheduling and sequencing are discussed subsequently, and are illustrated in Figure 1.

![Diagram of planning, scheduling, and sequencing](image)

**Figure 1: The demarcation between planning, scheduling and sequencing**

### 2.1 Planning

In production planning (for example MRP) the amount of required production in a specified time horizon is determined [Thomas and McClain, 1993]. Typically, the output of planning consists of the following plans [Bertrand et al., 1990]:

1. **The aggregate delivery plan.** This plan states the planned deliveries.
2. **The capacity usage plan.** This plan states for each capacity resource the required effective use in terms of hours per period in the planning horizon.
3. **The capacity adjustment plan.** This plan states for each capacity resource the adjustment of the available hours per period in the planning horizon.
4. **The aggregate inventory plan.** This plan specifies the planned inventory for each production stage in the planning horizon.

Thus, the output of planning for the manufacturing process consists of material requirements in time. These requirements are passed to the lower logistic control levels, i.e., scheduling.

### 2.2 Scheduling

The output of planning, i.e., material requirements in time, is the input of scheduling. Production scheduling focuses on the logistic control of individual production units or shop floors. A production unit is an outlined part of the production process, that on short term is self-contained regarding the use of resources. The production unit is responsible for the timely production of a specific set of products [Bertrand et al., 1990]. Scheduling is defined by Volcano et al. (1992) as: “a plan with reference to the sequence of and time allocated for each item or operation necessary to complete the item.” Hence, scheduling determines for each resource (which is in many cases only machine-capacity), the points in time when operations are executed, **under the following constraints:**

- Finite capacity resources,
• Precedence relations,
• Start-dates and due-dates of work-orders.

These constraints that are satisfied by scheduling serve to illustrate the difference between scheduling and planning, where these constraints are not necessarily satisfied. We will make a distinction between two possible aggregation levels of scheduling:

1. **Resource level.** Work-orders are scheduled for each resource. This type of scheduling leaves scarce decision freedom to the shop floor.

2. **Shop level.** Work-orders are only scheduled for the shop. This type of scheduling leaves some decision freedom to the shop floor.

The scheduler should optimise (or at least satisfy) certain goals that are deduced from organisational objectives, for example: service level; resources utilisation; set up costs; stock costs; throughput times. After scheduling, the schedule is transferred to the production unit. The implementation of a production plan or schedule is often referred to as *dispatching* [Thomas and McClain, 1993].

### 2.3 Sequencing

At each workcenter in a production unit, every time a work-order is completed, a decision has to be made which order will be processed next; this decision is referred to as *sequencing*. If the schedule is made at the resource level, as discussed in the previous section, the production schedule already assumes a specific sequence. In this case, if the schedule is carried out literally, no separate sequencing decisions have to be made. However, if the schedule is made on shop level, all sequencing decisions are left to the shop floor.

### 3. Common Disturbances

In practice, the planned or expected logistic performance of production units often deviates from the achieved performance. It is remarkable that most of these deviations are negative, which means that the actual performance is worse than the expected one. So, expectations about future performances are often too optimistic.

At the shop floor, many everyday disturbances occur that may cause (mostly negative) performance deviations. These disturbances can be divided in three categories: Capacity, work supply, and orders. An overview of disturbances is given in Table 1. These disturbances are discussed below.

<table>
<thead>
<tr>
<th>Disturbances</th>
<th>Examples</th>
</tr>
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<tbody>
<tr>
<td>Capacity</td>
<td>1. Machine breakdowns</td>
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<td></td>
<td>2. Preventive maintenance</td>
</tr>
<tr>
<td></td>
<td>3. Idleness on machines/operators</td>
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<td></td>
<td>4. Alternative routings</td>
</tr>
<tr>
<td></td>
<td>5. Vacation, illness, schooling of operators</td>
</tr>
<tr>
<td></td>
<td>6. Operator–flexibility</td>
</tr>
<tr>
<td>Work supply</td>
<td>1. Extra orders, caused by scrap, rework</td>
</tr>
<tr>
<td></td>
<td>2. Rush orders</td>
</tr>
<tr>
<td></td>
<td>3. Order release policies</td>
</tr>
<tr>
<td>Orders</td>
<td>1. Availability of materials, tools, and drawings</td>
</tr>
<tr>
<td></td>
<td>2. Differences between pre–calculated and actual processing time</td>
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<tr>
<td></td>
<td>3. Fulfilment of sequencing rules</td>
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</tbody>
</table>

*Table 1: Common disturbances.*
Capacity disturbances can be divided in disturbances caused by machine–capacity and disturbances caused by operator–capacity. Examples of disturbances of machine–capacity are: machine breakdowns; preventive machine maintenance; capacity idleness due to insufficient work supply; the use of alternative routings in case of multi–skilled machines. Examples of disturbances of man–capacity are: vacation; illness; schooling. There can also be a gap between the available and actual use of multi–deployment of operators, due to the use of available specialisms.

The planned or expected work supply can deviate from the actual work supply in terms of volume (in number of hours to be processed), and of arrival moments. The real work volume can differ from the expected volume due to, for example, extra work caused by scrap, or the arrival of rush orders. The order release policy that determines the arrival moments of orders in the shop may also have an impact on the performance. For example, when orders are released to the shop floor at the beginning of a week this may cause a large amount of work–in–process at some workcenters, resulting in long order waiting times.

Order related aspects that delay the progress of individual orders are for example the unavailability of: raw materials; order specific tools; order specific drawings. Processing times that are estimated by the work preparation department may be incorrect. Rescheduling of orders (in time as well as amount) influences the progress of other work, e.g., due date changes affect the progress of all other orders if a due–date oriented sequencing rule is used. Although in many production departments a sequencing rule is used, that often is quite simple, operators may deviate from this rule, and thereby influence the performance (especially the performance measures directed at time, e.g. delivery reliability). If scheduling implicitly defines a sequence, as has been stated in 2.3, the fulfilment of the schedule, will also be influenced by these behaviour deviations. The underlying decision behaviour will be discussed in Section 5.

To our experience, most of the above disturbances are known to practitioners. Often, the disturbances are qualitative in nature rather than quantitative, which makes validation of the effect of a disturbance on performance difficult. For example, a production shift leader may explain a disappointing throughput by unexpected operator absenteeism. This may sound reasonable, but this explanation rarely is being tested quantitatively. Schedulers may experience a bad order delivery reliability in a specific measurement period. This may be due to a lot of re–work that had to be done, but the impact is difficult to quantify.

In short, the disturbances that occur at the shop floor result in deviations between expected values of model variables and the real values, but the exact influences are hard to grasp. It can also be concluded that most of the above–mentioned disturbances have a larger impact on the short term than on the medium/long term performance. Because most of the existing performance models focus on the steady state performance only, these disturbance factors either are not taken into account, or only in an aggregated way.

This implies that quantifying the model variables is a difficult task. Someone who wants to evaluate the performance of the shop floor with a model should integrate the influence of the disturbances in the other variables in one or another way. A common restriction is that only the average impact of certain disturbances can be incorporated into the steady state models. For instance, when the average amount of scrap is known, one can incorporate scrap by using larger lot–sizes. There are also other disturbances, such as sudden machine–breakdowns and unavailability of production tools, that are not put into performance models for estimating the logistic performance. Because these kinds of events only seldom take place, this actually forms no restriction.
4. Shop Floor Models

4.1 Predictive Performance models

Models directed at the logistics performance of production units have a predictive or evaluative function in the sense that they estimate a shop floor's future performance or ex-post predict which performance could have been achieved. Suri et al. (1993) divide performance evaluation models into three categories:

1. Static (allocation) models. These models add up the total amount of work allotted to each capacity resource, and estimate the performance from these totals. An example is the rough cut capacity planning module of MRP.

2. Advanced dynamic models. In these models, some of the dynamics, uncertainties, and interactions in the production system are taken into account, but only in an aggregate way. The content of the model is based on analytical techniques from stochastic processes, queuing theory, and reliability theory. These kinds of models are very popular today, because they can be used for rapid decision making.

3. Detailed dynamic models. In these approaches, the manufacturing processes are manufactured in considerable detail. Examples are deterministic scheduling models and simulation models.

A characteristic of these kinds of models is that they usually provide estimates of steady-state performance measures only. So, only long term, average performances are estimated. All kinds of daily disturbances can only be incorporated in the models in an aggregate, average way. This is affirmed by Lin et al. (1992) who state that “due to the lack of viable modelling techniques, abnormal situations at the operational level in a dynamic environment cannot be handled by shop floor production control systems that are only applicable to steady state-performance.”

4.2 Schedule Performance

The problem of measuring schedule quality has only recently been recognised as a very complex problem [Kempf et al., 1993]. Two basic criteria that are also mentioned in Section 4.3 are validity and robustness. Beyond the conditions of validity and robustness, assessing the quality of a schedule is very difficult. A measuring technique for example would have to take into account:

1. Normative Performance. To objectively assess the quality of a schedule, we need to know the normative performance of the shop floor. However, it is not possible to calculate this normative performance. Therefore, quality measures always have to be relative, i.e., compared to past performance.

2. Measuring horizon. When measuring the quality of a schedule, the question arises which time horizon should be evaluated. If a specific time horizon is chosen, the possibility exists, that a positive performance in the current schedule affects a negative performance in the coming periods.

3. Measuring level. It is possible that the scheduler is able to improve the performance of the schedule while reducing the performance of other production units.

Until adequate schedule quality measuring techniques are available, we have to rely on assumptions about the success of scheduling techniques in practice. A scheduling technique is
already assumed successful if the scheduler in question uses the technique, without major problems as mentioned in Section 4.3. This seems to be a basal criterion, however, in practice, even this fundamental demand often is not fulfilled.

### 4.3 Techniques

As a result of the research in production scheduling, a large amount of scheduling techniques and information systems based on these techniques is available. Some well-known techniques are:

- **Priority dispatching rules.** These rules are based on work-order characteristics, e.g., processing time or due-date. An example of a dispatching rule is the Shortest Processing Time (SPT) rule. If a job is completed at a work-center, the job with the shortest processing time will be processed next.

- **Optimisation techniques.** These techniques find an optimal schedule by enumerating all possible schedules and choosing the best one according to a specific performance criterion, e.g., make-span. Examples are: Branch and bound techniques, mathematical programming.

- **Bottleneck methods.** This technique first makes a distinction between bottleneck and non-bottleneck resources. Then the bottleneck resources are scheduled to ensure maximal utilisation. An example is Optimised Production Technology (OPT).

In practice, priority dispatching rules are the most broadly used techniques. These priority rules often belong to implicit scheduling guidelines that a scheduler uses, unaware of their origin in production control theory. To illustrate the applicability of scheduling techniques in practice, we will make the following distinction within the above-mentioned techniques:

1. **Order characteristics.** This category is mainly filled with priority dispatching rules. Decisions about the sequence of work-orders can be made by operators at the shop floor level.

2. **Schedule characteristics.** This category is filled with techniques that generate schedules according to a specific performance criterion, e.g., service-level. The schedule is supposed to be (near-)optimal according to this performance variable.

This distinction between scheduling techniques emphasises the difference in the organisational decision making level of scheduling. A priority dispatching rule can be executed by the operators at the shop floor level and is thereby much more robust than techniques of the second category, which are executed by the scheduler. This will be explained below.

Techniques that strive to optimise the schedule by a performance variable suffer from the so-called final-state problem (Workman et al. in review). This means, that a small change in the status of the shop floor causes major changes in the optimal production schedule. Because changes in the status of the shop floor happen very often, these techniques continuously have to generate completely new schedules.

Another problem that can be associated with the second category is invalidity of the production schedule. The above-mentioned techniques rely on a certain model of the shop floor to generate a production schedule. However, because of the very complex nature of shop floors, many assumptions have to be made to enable modelling. Because of these assumptions, schedules are generated that apply to a model of the shop floor that does not as such exist in
practice. Therefore, automatically generated schedules have to be ‘translated’ by a human scheduler.

Regarding these problems, one could conclude that scheduling techniques that use schedule characteristics to generate production schedules are inferior to techniques that use order characteristics. However, the advantages of techniques that use order characteristics go along with disadvantages. Priority dispatching rules are not very ‘smart’ and they generate schedules that are far from optimal with respect to a specific performance criterion. These rules only use local information, which leads to local optimisation, i.e., insensitive to the overall state of the production unit. However, in some production units this is subordinate to the robustness of the technique.

5. Human Factors

The gap between scheduling and shop floor practice, and the resulting limited applicability of scheduling techniques in practice, has the effect that scheduling is still a human task in most companies. However, practitioners in production scheduling are often convinced that human scheduling is far from optimal. Here the question arises if and how the scheduling task should be considered for automation. Because some elements of scheduling are very hard to automate (e.g., negotiating with suppliers about delivery dates), humans will probably continue to play a key role in scheduling for a long time. Therefore, decisions about the allocation of tasks between the scheduler and techniques have to be made. This allocation should be closely guarded, as automation can starve cognition [Price, 1985].

The task allocation problem has driven human factors research in production scheduling [Sanderson, 1989]. An important lesson to be learned from past studies is that the question: Which is “better,” man or machine scheduling? is not relevant. Designers of scheduling techniques should take into account that human cognitive abilities fit well with some elements of the scheduling task, while other elements cause difficulties. Therefore, to improve production scheduling, task elements that cause task complexity [Wood, 1986; Campbell, 1988; 't Hart and Wiers, 1994] should be considered for automated support. Other tasks that the scheduler performs well—e.g., communicating, reacting to new situations—should preferably not be automated. In the following we will outline weaknesses and strengths of the cognitive abilities of humans.

5.1 Limited cognitive abilities

The production scheduling task imposes some specific cognitive abilities from human schedulers. Production scheduling can be characterised as a complex task by the following dimensions [Wood, 1986; Campbell, 1988; 't Hart and Wiers, 1994]:

1. Limited decomposability. If a task has too many elements to process simultaneously, the human will decompose the task into sub-tasks that are processed subsequently, because the human has a limited short-term memory [Anderson, 1990]. However, the interrelations between task elements should allow for decomposition. The scheduling task has a very limited decomposability of task elements. Task elements of the scheduling task are: work-orders, capacity resources, etc. The scheduling of a single work-order effects many other work-orders.

2. High dependency. The schedule of week \( t \) influences the schedule in week \( t+1, t+2 \), etc. However, for the human scheduler it is rather difficult to ascertain these influences, because of his or her limited long-term memory accuracy [Anderson, 1990]. As a result, the scheduler will fix problems now, and at the same time create problems in coming periods.
3. **Limited analysability.** The task elements within scheduling are mostly not of a deterministic nature. Machines break down, processing times vary, operators get sick, prognoses are unreliable, etc. Very little can be done about these uncertainties by the scheduler, except for having buffers. However, most production systems do not have the financial means to adequately buffer against these uncertainties.

4. **Limited controllability.** To be able to monitor and improve the performance of scheduling, the scheduler has to know the actual performance and the normative performance of the shop. However, many schedulers do not receive feedback about their actual performance, and it is impossible to calculate a normative performance. Even when performance feedback is present, the scheduler will have great difficulties to improve his or her decision behaviour, because the relation between action and effect is not clear [Brehmer, 1980; den Boer, 1994]. To enable learning in complex tasks, cognitive or learning oriented feedback is required [Jacoby et al., 1984; Early et al., 1990; Johnson et al., 1994], but virtually nowhere to be found.

5.2 **Advanced cognitive abilities**

Humans are very well equipped to cope with many ‘soft,’ qualitative task elements. Humans are superior to existing scheduling techniques and information systems regarding the following characteristics [McKay et al., 1989]:

- **Flexibility, adaptability and learning.** Humans can cope with many stated, not-stated, incomplete, erroneous, and outdated goals and constraints. Furthermore, these goals and constraints are seldom more stable than a few hours.

- **Communication and negotiation.** Humans are able to influence the variability and the constraints of the shop floor; they can communicate with the operators on the shop floor to influence work-order priorities or to influence processing times. Humans are able to communicate and negotiate with (internal) customers if work-orders are delayed, or communicate with suppliers if materials are not available as planned.

- **Intuition.** Humans are able to fill in the blanks of missing information required to schedule. This requires a great amount of ‘tacit knowledge.’ At the time of collecting this knowledge it is not always clear which goals are served by it.

Apart from these cognitive strengths, humans often prefer their own judgement to the application of models, especially if they are confident about their expertise [Kleinmuntz, 1990]. This confidence certainly applies to scheduling, because the scheduling task requires a high level of expertise. Schedulers communicate intensively with people on the shop floor, and some have even advanced from shop floor working to a scheduling position. However, decisions made by overriding formal techniques are not necessary superior to the decisions suggested by these techniques, although these decisions are hard to compare, as has been stated in Section 4.2.

5.3 **Implications of Human Factors to Scheduling**

The implications of the preceding three sections for humans interacting with techniques in scheduling consists of the following: The reason for **applying a technique** lies in the cognitive weaknesses of human schedulers which are amplified by production units where the scheduling task is complex, i.e., where the schedule should be constructed according to performance variables. The reason for **giving decision responsibility to the scheduler** lies in the cognitive strengths of humans, which are especially employed in production units where scheduling tasks are not complex, i.e., where the schedule should not primarily be constructed
and optimised, but continually re-constructed by reacting to short-term disturbances and events.

6. Production Control Structure

The structure of production control has a considerable effect on shop floor scheduling. In this section two issues regarding this effect will be discussed. First, the organisational structure and responsibilities of production control are discussed. Second, the problem of how and when to measure and monitor logistic performance will be discussed.

6.1 Organisational Goals

The different organisational levels of production control often go along with different and possibly conflicting performance goals. Regarding logistic performance, typical performance norms are: delivery reliability; capacity utilisation; stock levels; order flow times. These norms cannot all be fulfilled at the same time. For example, a well-known conflict between performance measures is the trade-off between utilisation level and order flow time. Logistic management has to decide which compromise of goals for these two variables should be set. Regarding these two performance criteria, a conflict may arise between Logistic management, who wants to achieve short order flow times, and Operations and Financial Management, who wants to achieve high efficiency, i.e., capacity utilisation.

A similar conflict can occur between the scheduler and the shop floor manager. The scheduler is generally responsible for delivery reliability, while the shop floor manager generally is responsible for the throughput and the capacity utilisation of the shop. These two goals are clearly in contrast which each other. The following two problems are caused by this conflict:

First, schedulers experience that they are hindered in their attempt to control the progress of individual orders. Their possibilities to influence the processes at the shop floor are usually restricted to changing the priority of single work-orders. The schedulers do not have possibilities to influence for example available capacity. More generally, schedulers are responsible for processes over which they do not have adequate control.

Second, as a result, performance evaluation may turn out positively for one function at the cost of the other function.

6.2 Long Term Vs. Short Term Goals

The reporting period influences the shop floor's performance by means of the feedback horizon. According to organisational psychology, people should receive feedback about their actions with the least possible delay [e.g., Brehmer, 1990]. However, the shorter the time interval of reporting, the more feedback is given, and the more decisions will be made to overcome problems that are inferred from the performance reports. This may lead to a short term focus and consequently to a nervous decision behaviour.

Here the problem of performance norms directed at the long term versus performance norms directed at the short term becomes visible. Because of common fluctuations in the performance of the shop floor—which are discussed in Section 3—there are periods where the performance is higher than the planned long term performance, and there will also be periods in which the performance is lower than the planned long term performance. According to these natural fluctuations, decisions aimed at compensating negative deviations at the short term are very often superfluous. Such decisions can be judged as overreacted and costly, because performance will return to the average level all the same [Globerson and Riggs, 1989].

To avoid the above-mentioned problems, performance targets at all levels should be realistic. This means that long term performance targets should only be used to evaluate the average performance over a long time period, while short term performance should be compared with realistic short term performance norms.
7. Discussion and Conclusion

In this section we will try to give some answers to the question how to improve scheduling, while avoiding the pitfalls described in the previous sections. Regarding the disturbances that were described in Section 3, we can ask ourselves if efforts, aimed at improving scheduling performance are justified at all. Apparently, the amount of disturbances at shop floors is that large, that schedules, and especially the sequences in these schedules, are not carried out. So, if schedules are not used at the shop floor, why optimise them? And what is the function of the scheduler in these situations, apart from “putting out fires?” Even if we assume that it is possible to construct a schedule that is carried out literally, the schedule in question still is suboptimal, i.e., optimising individual production units instead of the total manufacturing process, and nervous decision behaviour will still occur as a result of the schedule horizon.

Therefore, to improve scheduling we think the focus should not primarily be aimed at improving schedules from an operations research point of view, especially in complex jobshops. First, organisational problems that were described in section 6 should be solved. The logistic goals at different levels of the organisation should be compatible. A priority list of performance criteria could be of use here. The procedures to evaluate someone’s performance should reflect these priorities. However, the problem remains how to measure performance correctly and objectively [Kempf et al., 1993], and what feedback horizon should be used.

A second way to improve scheduling is to attack the disturbances that were mentioned in Section 3, while at the same time installing more flexibility in the shop. This can be achieved by increasing the number of tools, procedures for checking the availability of drawings and raw materials, and technically decreasing the amount of machine disturbances. Furthermore, the availability and quality of materials can be improved by better co-ordination between the (internal) supplier and the production unit. Multi-deployment of operators, machines, and materials will increase flexibility. Also, decreasing the complexity of the production unit by standardising, and thereby decreasing the number of: materials, processes, end-products, etc. can be used to improve flexibility.

There are two ways to avoid problems regarding schedule fulfilment. In the first solution the shop floor is forced to literally carry out the schedule, and behaviour deviations are penalised. However, this solution would make the job of shop floor workers less interesting and sometimes even frustrating, for example when they see obvious solutions for problems in the schedule which they are not allowed to carry out. A second solution employs performance feedback to improve the decision behaviour of the shop floor workers as a group. The actual performance versus the performance achieved if the schedule would have been fulfilled literally is a possible form of feedback.

If the above solutions do not improve the decision behaviour of production scheduling, we think that the presence of a schedule is ineffectual. Here, to control production at the shop floor, a sequencing priority rule can be used. This is possible because in aggregate planning it has already been determined which orders have to be produced. Therewith, the scheduler’s task is finally recognised as an order-tracking task.

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