5. Production Process Scheduling

5.1 Introduction

A detailed description of the steelmaking scheduling problem can be found in German language in Dorn et al. [Dorn93]. The main characteristics are shortly restated here to explain the different scheduling objectives.

Steel is produced on two continuous caster units, one being double stranded. Each day a cast sequence of about 35 charges (jobs) is scheduled for one caster over the next 24 hours. Hot pig iron is delivered from the blast furnace to the LD-converters. The steel is then poured into ladles, processed further in secondary metallurgy aggregates, and finally delivered to the casters. The casters produce continuously strands of steel that are cut into slabs of specific length. Although the steel is produced in different aggregates in a fixed flow, the casters are the bottleneck resource of the shop. The tundish, a part of the caster, has to be maintained after approximately 240 minutes. The maintenance takes approximately 100 minutes, therefore a second tundish is used while the first is maintained.

The main criteria that constrain the sequence of charges are compatibility constraints between jobs. At least three compatibility aspects must be considered in order to optimize production quality:

- The *steel grade* (the chemical analysis) of subsequent charges must be similar.
- The *casting format* may vary only within certain limits.
- The *degassing procedure* in the secondary metallurgy aggregates must be compatible between subsequent charges.

The rules are explicitly given in a crisp form, but human operators have been observed to ‘break’ or relax these a-priori hard rules and to implicitly make trade-offs in 20 % of their decisions. Their behavior can be adequately modeled by using fuzzy constraints.

To optimize the production, the casters should process the steel without interruption. Various operations can help when hard barriers otherwise would be broken. These include inserting a steel plate into the strand to separate the different qualities such that they do not mix too much, or to prematurely exchange the tundish in use with a second one. However, both operations have associated costs. If the tundish-exchange caused by quality considerations can be combined with a tundish-exchange because of tundish maintenance considerations, these costs can be minimized. The most expensive operation is to stop and then setup from scratch the whole casting unit. This takes a lot of time, but is sometimes necessary to do maintenance on the caster, or to produce certain difficult jobs.

There are soft temporal release-date and due-date constraints for certain jobs that should be delivered still hot to a subsequent plant. However, since there are (limited) warm-holding places available, the exact observance of temporal constraints is not obligatory. Additionally, the temporal constraints can be renegotiated with subsequent plants, and sometimes it is possible to exchange the temporal constraints of two jobs.

Generally speaking, it is possible to find a feasible schedule. However, criteria such as produced quality, tundish usage time, quality separating operations, number of setups and maintenance intervals of machines, release-dates, due-dates, and even such aspects as work-load of staff should all be optimized. Additionally, rescheduling has to be done quite frequently when some production parameters change due to machine breakdowns. In the past, most human errors were made in these rescheduling situations since time to think is scarce and the situation worsens rapidly (e.g., forgetting for some time a waiting aggregate, resulting in longer waiting times or worse qualities for certain jobs) if no action is taken.

In a first expert system approach, Stohl et al. [Stohl91] applied a constructive domain heuristic to the problem. Although the system found good feasible solutions, Stohl et al. believe that the solutions could be further improved, especially since constraints could only be broken through explicit user-intervention, and because the relaxing of constraints was not evaluated.

5.2 Constraints in Steel Production Scheduling

A schedule has to satisfy as good as possible a variety of restrictions and constraints. For general classification and description of constraints please refer to Chapter 3 and Chapter 4. In this section we will examine the most important constraints in the steel-making environment.

❑ *Compatibility Constraints*

The chemical analysis of a heat includes about 42 chemical elements, but usually only 8 main elements are considered. For good steel quality the steel grade of a charge should not be polluted by residuals of the last heat in the electric arc furnace. Actually, 8 - 9 % of all heats are destroyed, because they meet not the required steel quality. Besides avoiding such destructions, the engineers are interested in not wasting rare elements. If a heat demands a high percentage of an expensive element, the next one should use as much of the residuals as possible. The engineers assume, that 3% of a chemical element in a heat remain on the wall of the furnace, and 3% of the difference of the elements in two consecutive heats will be assimilated by the second heat. Other compatibility constraints are given by the fact, that the casting format may vary only within certain limits.This situation leads us to formualte compatibility constraints on subsequent heats in order to get an optimal job sequence on the continuos casters.

❑ *Temporal Constraints*

Some steel qualities require the steel to be hot for further treatment in other aggregates of the plant. These secondary metallurgy aggregates can be served within a tolerance of ± 2 hours. Although these temporal requirements are not really hard, it is desirable to satisfy these constraints in order to reduce time, and in the same step, cost. There exist some exceptional temporal restrictions, as e.g., for weekends, etc. We will not consider this extraordinary situations in our model. The treatments in the aggregates behind the blast furnace are usually shorter than the duration of melting. However, very high qualities need more treatment and for that more time. So one objective is to keep these intervals as small as possible. The satisfaction of temporal constraints is, generally speaking, a secondary goal. The main restrictions are given by the properties of the process; violating the chemical constraints is much more expensive than a small due date violation of a job is.

❑ *Capacity Constraints*

Of course none of aggregates in a steel plant has endless capacity. Resources are limited and machinery has to be maintained periodically. One objective is to achieve a uniform load distribution over the planning horizon for machines and workers. If an amount of steel that does not make a full heat is ordered, it can be combined with others of compatible quality. Another capacity restriction is given by the fact, that CC-3, one of the two casters, is single stranded, and the double stranded CC-4, the second casting unit, is able to cast two subsequent heats simultaneously as long as they have an identical chemical analysis. This has to be considered when a schedule is constructed.

5.3 Schedule construction

In most cases a feasible schedule can be constructed. However, a primary source of difficulty in constructing good schedules stems from the conflicting nature of the objectives. In Chapter 2 we have seen some strategies to solve (partial) constraint satisfaction problems. In manufacturing industry such as steelmaking, the distinction between commercial viability and failure often lies in the ability to control the production process through efficient scheduling. Due to the fact that it is usually not possible to perfectly fulfill all objectives when building new schedules, we try to partially fulfill the objectives. Our approach to reduce the complexity of the problem is achieved by considering only a small subset of objectives The satisfaction degree can then be used to evaluate the achieved compromise.

As we have seen in 5.2, not all constraints have the same importance; certain objectives are prioritized, therefore it is necessary to weight their satisfaction with importance factors. One especially straightforward way to achieve these two aspects of scheduling problems - to satisfy constraints to a certain degree, and to take into account relative importances - is the modeling of these constraints through fuzzy constraints.

Additionally we have to consider the timeliness requirement a scheduler has to meet. If we assume, that 45 jobs have to be sequenced for one production line, we would theoretically have to check 45! or more than $1.19622211 \times 10^{56}$ possible sequences of jobs for constraint violations. So we want a scheduler to find an approximate *good* solution before a certain deadline, even when this solution may be suboptimal. In combination with fuzzy constraints and the evaluation of their gradual satisfaction, heuristic search methods can be very efficiently guided to find a good schedule.

The OptiFLIP++ library described in Chapter 6 provides a variety of heuristic optimizing algorithms:

- ⇨ a tabu list min-conflicts repair based hill climbing heuristic
- ⇨ a min-conflicts repair based iterative deepening heuristic
- ⇨ a min-conflicts repair based random search hill climbing heuristic
- ⇨ a min-conflicts repair based genetic algorithm heuristic

All algorithms are repair based and have several variants and different parameters. The conflict identification function is used together with a domain dependent repair operator set to quickly choose one of them that will most probably minimize conflicts for a given situation. If we abstract from implementation, the scheduler works as follows:

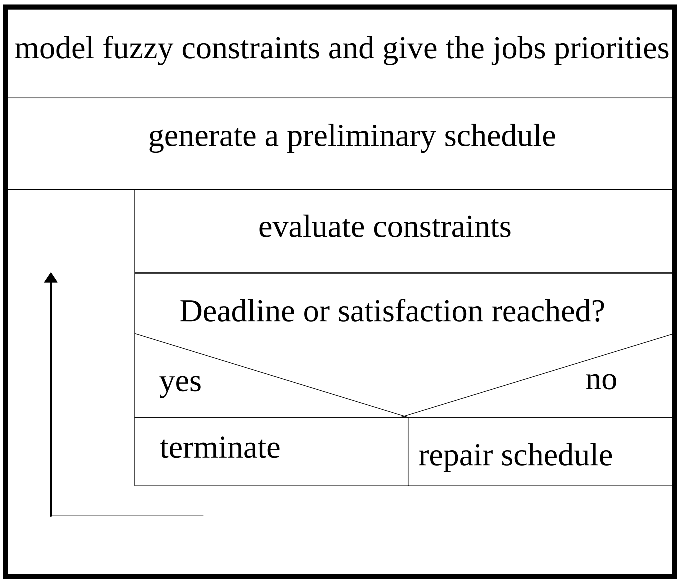

Figure 5.1: heuristic search for a good schedule

The evaluation of a schedule is based on the evaluation of the constraints and of their weighted aggregation. In a first step, a preliminary schedule is generated, often using prioritized jobs or items. In the steelmaking environment this applies to very difficult jobs or jobs with higher importance. The preliminary schedule is then repaired gradually by iterative improvement methods. This methods are search methods that start with an initial solution and try to improve this solution by local modifications. Such improvement could, e.g., be achieved by the exchange of two adjacent jobs, the move of an operation from one machine to another one with the same capabilities, and more. To modify given schedules, *scheduling tasks* are used to transform a schedule in a new similar one. To decide whether an improvement is achieved by such a scheduling task, the old and new schedule must be compared by the evaluation of both schedules. Smart algorithms try to improve a solution by local modifications without getting trapped in local maxima or minima. An outline of the basic concepts of these techniques can be found in section 2.5.2. The ‘desirability’ of a schedule is given by the degree to which it simultaneously satisfies all the goals and constraints.

5.4 Conclusion

The idea behind our methodology to redefine the various constraints through fuzzy constraints and to apply heuristics in the optimization process is to allow an easier modeling of the activites of human scheduling experts. The described techniques lead to shorter development cycles for scheduling systems an the knowledge representation becomes easier. Of course, this section cannot give a complete description of the steelmaking process, but we got some idea on its complexity and why it is useful to combine fuzzy constraints and heuristic optimization strategies. In the next chapter we will present the *FLIP++ libraries that are actually an implementation of the concepts we introduced so far. In Chapter 7 we will present a CSI(C&F)-example referring to the steelmaking environment described in this chapter.