A flexible decision support system for steel hot rolling mill scheduling

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Abstract

A steel hot rolling mill subjects steel slabs to high temperatures and pressures in order to form steel coils. We describe the scheduling problem for a steel hot rolling mill. We detail the operation of a commercial decision support system which provides semi-automatic schedules, comparing its operation with existing, manual planning procedures. This commercial system is currently in use in several steel mills worldwide. The system features a very detailed multiobjective model of the steel hot rolling process. This model is solved using a variety of bespoke local and Tabu search heuristics. We describe both this model and the heuristics used to solve it. The production environment is highly unstable with frequent, unforeseen events interrupting planned production. We describe how the scheduling system’s models, algorithms and interfaces have been developed to handle this instability. We consider particularly the impact on existing planning and production systems and the qualitative improvements which result from the system’s implementation.

Keywords: Scheduling; Decision support systems; Modelling; Heuristics; Implementation; Steel

1. Introduction

A steel hot rolling mill produces steel coils by subjecting slabs to high temperatures in a furnace and then subjecting them to high pressures through a series of rolls. The rolls which are in contact with the hot steel band become worn quite quickly and so planning takes place in shifts of a few hours. After each shift some or all of the rolls must be replaced.

The planning problem for a steel hot rolling mill is a complex problem involving several groups of machines and personnel. Slabs must be moved to the furnace area using manual or semi-automatic cranes. The movements of these cranes may be a process bottleneck. After heating in the furnace they must pass through a series of rolls. Changing the pressure settings of these rolls introduces a risk that coil
quality standards may not be attained. This risk increases with the magnitude of the jump in dimensions and hardness between adjacent coils in the sequence. The programme for each shift has a particular shape due to the need to initially warm up the rolls and then roll difficult (wide, thin, hard) coils while the rolls are fresh before decreasing width due to marking at the edges where a coil meets each roll. This gives the width profile of a programme a coffin shape and we will use the words coffin and programme interchangeably throughout this paper. Several commercial objectives must also be satisfied. Coils must be delivered on time and rush orders must be accommodated.

Within a steel plant the first semi-finished product which may be placed in inventory is the slabs which are used by the hot rolling mill. Whilst any planning system may not be considered in isolation from the operations of the whole steel plant, the fact that, in many steel plants, a hot rolling mill uses mainly stock from an inventory means that installing a computerised planning system for this problem in particular is a relatively painless way for a steel mill to gradually computerise scheduling.

Due to the complexity of the problem it is generally solved manually, or with only a small amount of computer intervention, using a sequence editor. The planner cannot consider all factors when generating a sequence in the short time available (1–2 h). He needs a very flexible sequencing tool which can use the power of the computer to generate the sequence according to the planners’ desires. Of course it is not reasonable to expect the planner to be able to exactly express his desires first time all of the time, so the computer sequencing tool must be fast enough to allow resequencing after changing the planners’ desires and to handle disruptions to the production process.

In this article we will describe a commercial semi-automatic sequencing system for steel hot rolling mills, which is now in use at several mills throughout the world. The automatic sequencer can not replace the human planner, but it does allows the human planner to build better programmes for a longer time horizon (3–10 programmes, representing up to four days production) in a shorter time (half an hour). The automatic planner will only propose programmes to the human planner. The planner can analyse the resulting programmes and add, remove or replace slabs before accepting the programme for production. It is no accident that these three moves are the ones considered in our heuristic. We will discuss this further later in the paper. It is important to stress three particular requirements of this problem:

- Given the nature of the sequencing problem (a complex constraint satisfaction problem with conflicting optimisation goals) it is unrealistic to search for ‘the optimal solution’. In practice the human planner is looking for an adequate solution given the difficulty of a given planning instance and the time and resources available for generating a schedule.
- The human planner will not accept a black-box sequencer. He has to be able to impose his decision criteria in an easy and natural way.
- Technical and commercial constraints and objectives undergo frequent change. The system must be designed in such a way that substantial and unforeseen changes may be incorporated into sequencing decisions with a minimal amount of system reconfiguration.

Not all sequencing decisions are based on slabyard data and customer data. Some decisions can only be made by the human planner (in response to incidents during production, priority orders, unavailability of production routes due to staff absenteeism, etc.). This can be done by allowing the human planner to define the slab selection criteria and let him decide on the coffin shapes to be rolled.
Our semi-automatic decision support system for hot rolling mill scheduling avoids the previously mentioned problems by:

- Applying optimisation techniques that use the available search time and return the best solution so far when requested by the user. In particular a “tiered” search approach allows the system to generate adequate solutions very quickly and improve these solutions further if more time is available.
- Allowing the planner to guide the sequencing algorithm. He is able to tune sequencer parameters to impose human decision-making on the automatic sequencer.
- Allowing the expert to adapt the constraints and goals of the sequencer in response to a changed technical or commercial environment.

In this article we will consider both qualitative and quantitative improvements due to our scheduling decision support system. In particular we consider the changes which are necessary for implementation at a client site, and the operational changes which installation and operation causes, as well as its impact on the overall production process. Our decision support system has proven that it can integrate well with a variety of planning practices, mainframes and decision support systems for scheduling other steel manufacturing processes.

The most difficult task for the human scheduler, and one which lends itself readily to automation, is to provide a sequence which minimises the changes in width, thickness and hardness between consecutive slabs. This sequencing task is related to the travelling salesman problem (Lawler, Lenstra, Rinooy Kan, &Schmoys, 1985) which is a well-studied problem of combinatorial optimisation. Several papers have been written about models and algorithms for particularly this aspect of the hot strip mill scheduling problem. Short-term planning systems for the hot strip mill in the literature may be divided into two groups. Assaf, Chen, and Katzberg (1997), Balas and Martin (1991), Jacobs, Wright, and Cobbs (1988), Petersen, Sørensen, and Vidal (1992) and Sasidhar and Achary (1991) all use optimisation techniques to generate nearly optimal solutions for simplified models of the hot rolling mill scheduling problem. Whilst these approaches may yield optimal or near-optimal solutions for a simplified model, these solutions may be difficult to implement in practice. Cowling (1995), Lopez, Carter, and Gendreau (1998) and Stauffer and Liebling (1997) propose more generally applicable models which are again solved using heuristic optimisation techniques. Both of these approaches have their respective merits. While the schedules generated using a simple model may often be hard to implement in practice, a better performance guarantee and a more transparent model and solution approach does carry certain advantages. More complex models must be solved using complex bespoke heuristics which take significant time and expertise to develop. Performance guarantees for these heuristics are really only possible in terms of scheduler satisfaction. All of the above papers consider principally the modelling and algorithmic approaches taken. In this paper we consider also the implementation and qualitative improvements which provided by use of the decision support system.

In Section 2 we discuss the environment in which the planning takes place and the goals which appear commonly in many steel plants. Section 3 considers manual planning systems and our scheduling decision support system. Section 4 gives details of new heuristic methods, which were used in our system, particularly to make the Tabu Search metaheuristic more robust. Section 5 discusses the user interface of the decision support system. In Section 6 we discuss the steps which must be taken in order to generate a plan using the system. Section 7 discusses results from both a qualitative and a quantitative standpoint and Section 8 considers the system changes which are needed and those caused by
the implementation of the decision support system within a plant. Finally, we present conclusions in Section 9.

2. The planning environment

In general data from three sources is required by the planner of a hot rolling mill. Details of customer order dimensions and qualities together with their due dates and priority are given in the order book. The slabyard database contains information about the slabs which are currently available for sequencing, together with their position within the plant. Plant specification and milling rules information is required by the planner upon which sequencing decisions are based.

The order book in general contains hundreds or thousands of client order specifications detailing the coil quality and dimensions required, together with details of order priority and due date. The order book is in general held in a computer database so that it may be readily used for commercial and planning purposes.

Steel slabs are held in one or more slabyards, large warehouses containing many piles of steel slabs. Each pile may hold up to 20 slabs. Steel slabs which are currently being cast may also be considered in this planning process, especially for hot-charging, when slabs are rolled while still hot after casting. A database is held of the position, dimensions and quality of each slab. This database is also normally computerised and held in such a way that required information is available to users within the steel mill as required.

The assignment of slabs to orders may be performed in two different ways. In a make to order environment each slab is immediately assigned to a client order after casting (or shipment) and thus each slab can be used to make only one coil. In a make to stock environment all slabs are regarded as being stock and each time a client coil order must be fulfilled, a slab is found in the slabyard having the required characteristics. Whilst most steel plant operate a make to order production philosophy, the long production lead times, large batch sizes, customer order cancellations and relatively high probability of missing customer production quality specifications mean that in practice there will also be significant amounts of stock to be attributed at any one time.

Plant specification and milling rules information gives the detailed physical specification of a mill, together with those features which are desirable for a planned sequence. This information changes dynamically from hour to hour and is changed by factory floor events such as machine failure and maintenance as well as commercial constraints such as rush orders. It is virtually impossible to maintain a computerised database of this information and in general this information is known only to a few individuals within the plant. In particular the planner should possess all the necessary information at the moment that he wishes to create a plan. The plant specification and milling rules detail the physical characteristics of the plant and the desirable features of a sequence. The rules may be regarded as being both objectives and constraints. Very few of them correspond to mandatory production constraints and most may be relaxed locally for a globally better sequence. There are many complex, interrelated rules some specified by measured machine characteristics and a larger number arrived at through years of planning experience. The rules cover eight main areas:

1. The commercial value of the rolled coils.
2. The difficulty of the coils to be rolled. Difficult coils should be rolled whenever possible and one of the system deliverables is that the reluctance of human planners to sequence these coils has been
3. The ‘shape’ of the sequence, which governs the subset of coils which are available for milling.
4. The difficulty and risks associated with changing mill set up between coils, particularly the pressure exerted by milling stands. Changes in pressure exerted are required when the width, thickness or hardness is different between adjacent coils in the milling schedule.
5. The requirement that the slabyard cranes have sufficient spare capacity to manage slab movement operations required by this sequence.
6. The requirement that furnace coverage be optimised to minimise energy consumption.
7. The requirement that rolling sequences should have approximately similar quality. Human planners would tend to place too much emphasis on early sequences and this is to be avoided.
8. Others which are unforeseen, and arguably unforeseeable, in a semi-automatic system.

3. Manual planning systems and our scheduling decision support system

In many steel mills planning is done by a small group of experienced planners and managers. Planning is performed one sequence at a time, where in general a sequence takes about the time of an eight-hour shift to set up and mill. Manual planning may take about one to two hours per sequence. There are several problems with such a system. The requirement that a planner must be present before a sequence may be planned may give problems during holiday periods or times of illness. Whilst a human planner has a great advantage in addressing point 8 above, the complexity of the sequencing problem means that some of the other points are barely considered during sequence planning. When many sequences must be generated at one time, for example for weekend and holidays, we observe that manually planned sequences exhibit a steady reduction in quality over time. Also the planner finds it difficult to generate sequences in very short time spans when these are needed in the event of machine failures or discrepancies between data held and material available.

The manual planning procedure in general proceeds pile by pile and addresses principally due date and width profile of the sequence, with some consideration of the thickness profile. This ignores some very important commercial, logistical and production objectives and while a manual planner can always be relied upon to generate a sequence, the sequence quality may be far below that which is actually possible.

A detailed investigation of planning practices in several mills has shown that a tool is needed to help the scheduler in generating sequences. Analysis tools must be available to guide the user in making informed decisions as to which coffin types should be scheduled. The planner must have the necessary tools to configure the system to deal with a wide range of possible production scenarios. In particular it must be possible to configure the system for a wide range of possibilities which it is not practically possible to foresee while the system is developed. The planning system should enable the scheduler to generate multiple mill sequences of uniform quality and thus avoid the problems associated with a short planning horizon. The system should generate sequences of sufficient quality for rolling in a few minutes in order to be able to plan in the event of machine failures and should be able to use available planning time to plan best possible sequences when the time is available. It should be possible to analyse different planning scenarios and generate “what-if” plans. This may
suggest where plant improvements would have the greatest impact and where production practices might be improved.

As a result of this investigation we have created the decision support system which is described in this paper, which takes into account all of the features 1–7 mentioned above and is configurable on three levels to address point 8. At the level of mill foreman, sequences can be requested and generated subject to current planning practices and settings with a limited range of configuration possibilities. At the level of planning engineer detailed settings and changes in planning practices can be configured. Many sequences may be planned at the same time, and each sequence is given equal priority. An important feature of our decision support system is that nearly all constraints are regarded as being ‘soft’ and so the user need not make the difficult distinction between a constraint and an objective. The system includes several tools which greatly simplify analysis of the data in order to guide the user in his choices. In addition its fast solution time means that it is possible to use the scheduling decision support system as an analysis tool—conducting several “what-if” experiments to find a good final solution.

4. Solution methods

Our solution method must satisfy two main requirements. It must very quickly provide the user an acceptable solution, in a matter of a few minutes. When further planning time is available, it must be possible to use this time to generate a sequence of higher solution quality. In order to satisfy these requirements, a heuristic has been designed which utilises three different solution paradigms.

In a first stage a ‘route-building’ heuristic is used to quickly build acceptable sequences. All coffin sequences are built in parallel. The heuristic quickly builds an initial solution based upon all user configuration rules. This route-building heuristic uses techniques based upon those of a manual planner. It proceeds first by ‘seeding’ each coffin using appropriate coils, to ensure that each coffin will have approximately the correct form. Then coils are inserted into this skeleton sequence using a heuristic analogous to the Clarke and Wright heuristic for the travelling salesman problem (Johnson & McGeoch, 1997). With the additional capability of a computer-based system to deal with all user requirements simultaneously and very quickly, acceptable solutions are obtained within a couple of minutes and are available for user analysis. The quality of these solutions would typically be a little better than sequences generated by manual planners, who would, however, take up to one hundred times longer.

In a second stage a ‘route-improvement’ heuristic takes the sequences generated by the route-building heuristic and improves them by perturbing them slightly. This perturbation is continued until no further improvement is possible and we have a local optimum. The procedure takes a few minutes to generate several coffin sequences, and its sequences are generally of significantly higher quality than those produced manually. The perturbation moves considered are:

1. Delete a scheduled coil from any coffin sequence
2. Add an unscheduled coil to any coffin sequence
3. Move a scheduled coil to another position in the same or a different coffin sequence.

Note that these three moves correspond to the three types of editing moves usually carried out by a manual planner. Hence a local optimum generated using these three types of move cannot easily be bettered by the manual planner, which increases user confidence in the system.
When, as is frequently the case, further improvement is required and further solution time is available, a Tabu Search metaheuristic (Glover, Taillard, Laguna, & de Werra, 1996) is used to guide the search procedure. This metaheuristic is a means of guiding the route-improvement heuristic. When the route-improvement heuristic arrives at a solution from which no perturbation improves the solution, this solution is a local optimum but may still be some distance from the global optimum value. Tabu search guides the route-improvement heuristic and enables it to escape local optimality and hence achieve a better optimum solution.

The distribution of coil dimensions (including hardness and rolling temperature) is extremely ‘lumpy’, with up to 80% of the coil population being grouped into several clusters (in terms of width, thickness, hardness and rolling temperature) and a remaining 20% being widely scattered. In order that our tabu mechanism can avoid cycling around a cluster of coils with similar dimensions, we introduce the idea of a similarity measure, based upon the difference in dimensions and physical properties between a pair of coils. The definition of similar here is configurable within the system to take account of the behaviour of the coil population at different plants. In order to avoid cycling, if a coil $c$ is inserted (say) into the sequence at some point then we not only make tabu deletion of $c$ for a certain time, but we also make tabu deletion of coils which are similar to $c$, i.e. those which lie in the coil neighbourhood of $c$.

We illustrate this idea in Fig. 1, where we have made the simplifying assumption that only coil width and thickness are important.

Relaxation of nearly all constraints results in a complex, multiobjective model to be solved. Here our objectives are:

1. Maximise the value of the coils rolled in the sequence
2. Minimise the jumps in dimensions between adjacent coils in the sequence
3. Minimise the edge wear on rolls which may mark future coils and reduce quality
4. Minimise the number of non-essential crane movements
5. Minimise the deviation from the ideal coffin shape

![Fig. 1. Use of similarity measure to determine tabu status.](image-url)
We have observed that standard adaptive memory techniques and diversification strategies for Tabu Search tend to result in cycling through the criteria, improving each in turn. Our similarity measure above means that a large number of coils will be tabu at any given time. To counteract this effect we need powerful aspiration criteria. The simplest aspiration criterion (A1 in Table 1 below) that we consider is that a perturbation is aspirated if it is tabu and carrying out the perturbation improves the total score. Our second aspiration criterion is that a perturbation is aspirated (type A2 in Table 1) if it produces a strictly better score in any of the five objectives given above. In order to make Tabu Search more robust in this case we introduce a third type of aspiration criterion (A3 in Table 1), the notion of multicroteria aspiration. Here we maintain at each point a list of all efficient solutions seen so far. Efficient solutions are solutions which are not dominated by any other (efficient) solution seen so far. Here a solution is dominated if there is some other (efficient) solution which is at least as good with respect to every objective criterion, and better in at least one criterion. In order to be able to quickly tell whether a solution is dominated, we need to maintain a list of all the efficient solutions seen to date. This strategy makes Tabu Search more robust, generating better solutions nearly all the time than simpler adaptive memory strategies. In Table 1 we can see, for a typical run of the heuristic using three different sets of parameters for tabu list size, that with this combination of wide-ranging tabu status the powerful aspiration criteria are used and the average size of the efficient set remains relatively small. Hence it is easy to check aspiration status for a tabu perturbation. Numerous experiments suggest that this combination gives rise to a very robust heuristic which generates good solutions over a wide range of different mill configurations and problem instances.

### 5. User interface

Any planning system must make it simple for the user to express his planning criteria then analyse the results generated and if necessary modify those criteria. To this end the scheduling decision support system has a powerful graphical interface. The interface is aimed at three different types of end users. In particular it has been observed that many of the current users of the system have never seen a windowing computer application before. The interface is thus built to be easy-to-use, even for users who have never before seen a similar application.

We can distinguish three different types of end users:

<table>
<thead>
<tr>
<th>Deletion tabu list size</th>
<th>Insertion tabu list size</th>
<th>Similarity measure</th>
<th>% of tabu moves considered</th>
<th>Aspirated (A1) %</th>
<th>Aspirated (A2) %</th>
<th>Aspirated (A3) %</th>
<th>Aspirated moves accepted %</th>
<th>Average efficient set size</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>6</td>
<td>10</td>
<td>21</td>
<td>1</td>
<td>28</td>
<td>30</td>
<td>3</td>
<td>3.8</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>10</td>
<td>25</td>
<td>1</td>
<td>24</td>
<td>30</td>
<td>30</td>
<td>7.4</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>20</td>
<td>36</td>
<td>1</td>
<td>18</td>
<td>24</td>
<td>28</td>
<td>11.7</td>
</tr>
</tbody>
</table>
5.1. Planner

Planners are part of the production planning department of the mill. They try to obtain the weekly/daily production goals by building milling programmes. The planner uses our system on a daily basis to build, edit and accept the milling programs. The user interface and operating procedures also make it possible for less qualified staff such as mill foremen to use the system to generate new schedules in response to, for example, production breakdowns. This is particularly useful when planners are unavailable, during night and weekend shifts.

The planner must have

- a list of configurations to start the planner (e.g. a configuration with limited slab yard access, a configuration during night shifts, a configuration for new or used backup rolls, etc.)
- analysis tools for the slab yard, the coffin shapes and the milling programs
- a slab selection module to impose current selection criteria upon the sequencer
- coffin type selection module to impose or select automatically coffin types for the programs to be generated
- sequencer to generate sequences automatically
- milling program editor to edit and accept programs for production
- tools to analyse the impact of a programme on the slab yard and production goals

Planners can not change milling rules, score functions or coffin shape definitions. When used by the mill foreman it is only necessary to select the appropriate configuration, which may be given a descriptively helpful name, for example “night shift emergency sequence after crane 1 breakdown”

5.2. Milling expert

The milling expert is an experienced engineer of the milling department. He has to be aware of all technical, logistical and commercial considerations of the milling process. He will have to apply this knowledge in order to tune the parameters and rules of the decision support system in such a way that the sequencer used by the planners reflect current milling practices and the current company strategy.

He defines:

- the company dependent data elements of the slab yard that can be used by the planner
- the selection categories that the planner can use to make his selection on the current slab yard
- the milling rules that have to be applied by the sequencer
- all coffin type descriptions that can be selected by the planner
- balancing of multiple goals used by the sequencer (customer order selection goal, jump and wear penalties, unpiling penalty, sequence form constraint violations)

Each time the planning conditions change, he will use the graphical interface to make modifications of the appropriate configuration files. Hence the milling expert can change the production characteristics of the mill and impose new commercial priorities.
5.3. OR analyst

The OR Analyst is only needed during the initial tuning phase of the planning system. He tunes principally:

- scoring and penalty functions (width/jump/thickness/temperature jump functions, due date function)
- wear function defining the complex relation between each coil’s length and its wear impact upon the rolls
- coffin length violation constraints
- edge wear violation constraints
- tuning of the Tabu Heuristic parameters (list length, neighbourhood size, aspiration criteria, etc.)

The most difficult task for the OR Analyst is to define the tunings in such a way that they can cope with a variety of slab yard populations. It is possible that more than one set of tunings may be required for this task although this has not been the case in practice so far.

6. Solution generation using our scheduling decision support system

Generation of a sequence using our decision support system requires four distinct steps to be performed (see Fig. 2). We give details of each step below.

6.1. Step 1: Slab selection

The user assigns a priority to each slab in the slabyard and its assigned coil. This is done via a simple graphical interface which allows the user to use the characteristics of a slab (and particularly due date,
client and slabyard location) to define its priority. In general the priority selection is performed by the milling expert on a regular basis (every few days) according to commercial priorities.

The planner has the ability to change selections at a less detailed level, for example in order to forbid a certain slabyard in the event of crane failure, etc.

The selection priorities given are used to give the sequencer a strong tendency to select slabs of high priority. However, note that the sequencer may make alternative choices where choosing a given slab might compromise other sequence characteristics, for example by giving very large jump in dimensions requiring a large change in roll pressure which may result in quality standards not being attained and roll damage.

6.2. Step 2: Coffin selection

Given the slab selection the planner must now decide how many coffin sequences he wishes to be rolled and the types of these sequences. To aid the planner in making an informed choice, he has available many possible graphical views of the coil population and of the impact of making a particular coffin sequence on the current population. The milling expert and planner make use of these views to decide which coffins to make based upon these statistics and upon many other factors unavailable to the computerised system. In the case of a sequence constructed by, for example, the mill foreman, it is possible to provide a very general coffin definition which will produce acceptable solutions without analysis.

6.3. Step 3: Programme generation

To start the system requires a simple button push. The user is kept informed of the solution progress and as soon as a solution is arrived at, it becomes available for user inspection, usually after a couple of minutes. When the decision support system is left for longer periods better and better solutions are arrived at and become available for user inspection.

6.4. Step 4: Programme evaluation

Once the required number of programmes have been generated, the user may inspect them using graphical displays of all coil dimensions (width, thickness, hardness, etc.) as well as other useful information (difficulty score of dimension changes, coil priority, etc.) in order to decide whether the solution is of sufficient quality to be sent to production. If at this stage (after only a few minutes planning) the sequence is of insufficient quality, the user can go back and make a new coffin selection or change slab priorities.

The user can also edit the programme by adding or removing groups of slabs, again using an intuitive graphical interface. In practice this is seldom necessary.

Once a programme of sufficient quality is arrived at, the programme can be communicated to the mill mainframe by a simple button push. This updates both the mill mainframe and the workstation decision support system. Programmes need not be sent to the mainframe, allowing the user to carry out “what-if” analysis.
7. Results

The speed of the system yields several advantages for the planner. Having initial results in a few minutes allows the planner to spend more time on less mundane aspects, such as gathering data concerning the commercial and technical status if the mill. He will also have time to generate several sequences, while changing some of his selection criteria or priorities in order to arrive at a globally improved sequence. This speed also allows the system to generate more sequences of a uniformly good quality than are possible through manual planning, allowing better coordination with upstream and downstream processes and more reliable forecasts of output.

Automating sequence generation means that results become repeatable, so that investing some time in defining the milling rules and other parameters will ensure that the same criteria are always considered in the same way. Hence management exert a far greater level of control over detailed sequence characteristics than they would when using idiosyncratic human planners. We may consider one particular example, based upon reality, of ‘Risky Ron’ and ‘Safe Sam’. Ron and Sam are both planners at the same plant, and Ron is very useful in cases where the slabyard population means that lots of bad rolling stand setups will be required to perform any sequence at all. For the same slabyard population, Sam is likely to construct very short sequences. For normal operation, when the slabyard is full, management prefer to use Sam’s conservative planning approach. Unfortunately Ron and Sam’s working hours are determined by a shift pattern and not by the slabyard population. Clearly in this case we may have configurations corresponding to the best characteristics of Ron and the best ones of Sam and use the appropriate configuration. Determining the milling rules, for use within the scheduling decision support system, from the planners experience, is a way to fix the expertise of decades of specialised workers in order to arrive at a more uniform production quality.

Of course the principal advantage of the system is in globally improved sequence quality. The minimisation of gauge, width, temperature and hardness jumps between adjacent coils in the schedule produces steel coils of higher quality with reduced risk of mill or furnace failure. The coffins generated have improved width profiles, giving improved coil quality due to better-controlled roll wear at the edges of rolled coils. Greater control allows better use of the rolls close to their wear limits and increased steel throughput between changes in expensive work rolls. We illustrate these results in Table 2. The three parameters given for each heuristic are (length of the Tabu list for coil deletion, length of the Tabu list for coil insertion, and the minimum distance between ‘similar’ coils). Note that we wish to minimise jump and edge wear scores (which correspond to coil quality), minimise the number of unpiling (crane)

<table>
<thead>
<tr>
<th></th>
<th>Jump (min)</th>
<th>Edge wear (min)</th>
<th>Coil value (max)</th>
<th>Unpiling (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual sequence</td>
<td>11915</td>
<td>28906</td>
<td>14287</td>
<td>47</td>
</tr>
<tr>
<td>Heuristic (4,6,10)</td>
<td>3841</td>
<td>305</td>
<td>16109</td>
<td>0</td>
</tr>
<tr>
<td>Heuristic (5,10,10)</td>
<td>3888</td>
<td>293</td>
<td>16386</td>
<td>0</td>
</tr>
<tr>
<td>Heuristic (6,12,20)</td>
<td>3888</td>
<td>293</td>
<td>16386</td>
<td>0</td>
</tr>
</tbody>
</table>
operations and maximise the value of the coils rolled in each sequence. Since the manual scheduler is not trying to adhere strictly to our performance measures, the table exaggerates slightly the difference in sequence quality, as perceived by the users of our decision support system. Nevertheless, in this case and all others to date, our sequences have been at least as good, and usually substantially better, than those generated manually. In this case the heuristically generated sequences were all generated in less than a tenth of the time of the manual scheduling process.

8. Implementation issues

Our decision support system is an open system where data formats, definitions, rules, coffins, selections can be user defined and user specific. It is possible, within only a few hours, to define data formats and to generate the first milling round for a steel plant starting from just raw data and limited information, thus allowing easy and cost-effective comparison with existing systems.

A further step in configuration consists in translating the rules which have been verbalised by the customer into the format required by our decision support system. The description of the rules in our system is written in a fairly natural language which may, with practice, be quickly edited by personnel at the client site to change settings and behaviour. Some further tests can be carried on with slab yards on floppy disks, to simulate the data feed from the mainframe, before any major hardware installation is necessary. It also makes possible a thorough evaluation of the system by rolling mill planning personnel on a standalone machine, possible at a remote site, without the hassle of integrating a new system to the plant computer network.

The decision support system has been implemented so that it can quickly accept data in a wide range of formats, through the specification of a format file. Experience has shown that given raw mainframe data and some information about commercial priorities, acceptable sequences can be demonstrated within a single day before going to full implementation. This easy acceptance of a wide range of data formats minimises the impact on plant mainframe systems and the effort required by IT personnel within the steel plant. A similar approach is used for outputting results from the workstation decision support system, giving easy integration with existing steel plant IT systems.

All rule files and definitions are written in a natural language that makes them easy to understand and easy to modify. Only the milling expert has access to the rules and settings definitions, the planner is not allowed to change them. The syntax is flexible, accurate and general enough to accept almost any requirements from different customers, and very different machine configurations.

There is only one link to the mainframe of the plant. As described above, our decision support system can run (during an evaluation phase for example) without this direct link to the mainframe. As the system goes on top of what already exists without replacing it, it is always possible to come back on the mainframe procedure or keep it as a back up procedure. This additional security is very important for safe pilot implementation of the system.

A system like the one we have described must go to several steps of acceptance. It is a new concept in work organisation for many plants: at senior management level, the concept of a separate workstation and local computer power (instead of a centralised mainframe) must be accepted. The mainframe architecture is more common, with a central database. This also implies some change in work organisation and some shift in responsibility. There is more local flexibility without having to go through the mainframe. There is more freedom to change configuration...
(a coffin shape for example), so perhaps less direct senior management control need be exercised and more local responsibility given. At the plant level there are two levels of responsibility: data accessible to the user (the planner) and data accessible to the expert (milling rules, tunings parameters). There must also be acceptance from the plant IT department which sometimes might be reluctant to use external software. However, note that the workload in systems change for the IT department in installing the decision support system is very light. There must also be acceptance from the schedulers who will be using the system daily. Some may initially fear the implementation of a new system at the beginning, but experience shows that after getting used to the system, and understanding how far it could help them, it becomes as easy and fun to use as a video game. The graphical user interface avoids the use of the keyboard and schedulers quickly become used to using the mouse.

Initially, our decision support system was intended to be used exclusively by engineers and trained schedulers, but is now currently and successfully used by mill foremen, who had not any previous experience with computers, after only a short familiarisation period.

A system like the one we have described uses a lot of information to run. This information is generally available on the mainframes but is rarely utilised totally to solve the planning problem. Our scheduling system makes better use of all the information available, and acts as an auditing mechanism for the mainframe data systems since the decision support system provides an independent check for mainframe data consistency and warns the user in the case of inconsistent data. However, there are also ‘default’ ways of ignoring inconsistencies so that planning may proceed without correcting any inconsistencies, or while maintenance is carried out.

9. Conclusion

We have compared manual planning systems for steel hot rolling mill planning and a widely used commercial system for decision support of the scheduling process. In several steel plants throughout the world, our decision support system gives consistently better results than a manual planning system. We have discussed the features of the system as well as qualitative and quantitative improvements and other issues arising from its implementation. In particular we have discussed how the use of a semi-automatic scheduling system may yield substantial tangible and intangible benefits, principally through the freeing up of scheduler time from the mundane task of coil sequencing. We have discussed particular aspects of the model and the robust local and tabu search heuristics used to solve the hot rolling mill scheduling problem and particularly how these are configurable on three levels to deal with instability in the production environment.

References


