FUZZY EXPERT SYSTEM TO PREDICT MAINTENANCE INTERVALS IN A CONTINUOUS CASTER*

W. Slany

Christian Doppler Laboratory for Expert Systems
E184/2, TU Wien, A-1040 Vienna, Austria, Europe
Phone: +43–1–58801–6123 Fax: +43–1–5055304
E-Mail: wsi@vexpert.dbai.tuwien.ac.at

SUMMARY

During short-term scheduling in a steel plant, one problem is to know beforehand how long equipment will be usable and when it will have to be maintained. The proposed system answers this question for a part in a continuous caster in order to inform another system that schedules short-term production. It uses fuzzy inference rules to process input data and to compute the life-expectancy of the part. Wheras human operators tend to use pessimistic values in order to be on the safe side, the system performs better in predicting the life-expectancy since it considers more types of influence and reasons with up-to-date information. For these reasons, the final schedule matches reality closer, avoiding vasted raw materials and production delays, while at the same time increasing product quality.

Both systems are currently developed in a joint project between the Austrian Industries Holding and the Christian Doppler Laboratory for Expert Systems.

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KEYWORDS

Expert system; fuzzy logic; maintenance; steel production; quality; scheduling; continuous caster; AI and knowledge-based systems; uncertainty management.

INTRODUCTION

One strategy when scheduling is to minimize tundish changes in casting sequences to extend the utilization time of each tundish. This time is mainly limited by wear. Another scheduling strategy is to assign heats requiring a quality separation in form of a tundish change as the last heat before the expected end of the tundish's utilization time. Both strategies require a "good" knowledge of the tundish's life-expectancy. Human scheduling experts normally play safe and assume a life-time of 240 minutes for one tundish. Problems arise when the real life-time is shorter than 240 minutes, or otherwise exceeded: This results in quality degradations or even the need to reschedule remaining heats, with possibly far-reaching consequences for delivery dates to customers. Additionally, in case of interruptions for unrelated reasons, e.g. machine breakdowns, knowledge about the remaining life-expectancy of the tundish helps rescheduling the production.

Optimal scheduling is therefore only possible when the tundish's life-expectancy is known in advance. A detailed analysis of the scheduling problem can be found in (Dorn et al., 1993). Mathematical-analytical methods as used in Operations Research approaches are often insufficient for planning problems. This is due to three reasons: The imprecise information in the production process, combinatorial complexity of the search space, and conflicting objectives for production optimizing. The combination of several knowledge-based techniques, especially approximate reasoning and constraint relaxation, is a promising way to handle these problems.

In (Slany et al., 1992) we use a case study to demonstrate how knowledge-based scheduling works with the desired capabilities to schedule short-term production. The applied knowledge representation technique covers the vagueness inherent in the problem domain by using fuzzy set theory. Based on this knowledge representation, the importance of jobs is defined. This classification of jobs is used for the straightforward generation of a schedule.

We introduce a control strategy which comprises several types of constraints, namely organizational, spatial, and chemical ones. This strategy supports the dynamic relaxation of conflicting constraints in order to improve the schedule. To show the benefits of this strategy, the generation of a schedule for one day is explained in detail.

In contrast, the present study deals only with one part of the scheduling problem, namely the computation of the tundish's life-expectancy. The critical part of the tundish is a pipe called spout. It reaches from the bottom of the tundish containing liquid metal into the mould of the caster. The hot metal flows from the tundish through the nozzle of this spout, itself immersed into the top of the strand. There the metal solidifies while advancing through the caster. At the surface of the liquid metal in the mould, aggressive slag attacks the immersed spout. To extend the utilization time of one tundish, the spout is increasingly immersed. Thus the slag-exposed surface of the spout changes with time, therefore avoiding a premature wear of the spout. However, if the bottom of the spout breaks away, the tundish becomes unusable, with all the consequences described above, e.g. it is well known that the very early stage of solidification determines the surface quality of a cast strip. Thus, when the spout breaks, the hot metal flows into the mould, without possibility to control the turbulences in the melt pool. There are some possible reactions when this happens, but generally speaking, avoidance of such an exception state is most advisable.

FUZZY EXPERT SYSTEM

The techniques needed for the construction of fuzzy expert systems can be found in (Negoita, 1985) and (Kandel, 1992). Related work on using knowledge-based systems for mold bath level control of continuous casters has successfully been carried out by (Sasabe et al., 1990). They had difficulties to maintain an optimal bath level by a PID controller and a slide gate controller with fixed parameters, because the characteristics of casting conditions fluctuate during operation. To solve this problem, an expert system has been applied to the mold bath level control system. In this traditional expert system, operator know-how regarding control parameter adjustment is represented in the form of a knowledge-base, and that knowledge-base is driven by an inference engine only when a significant fluctuation of the mold bath level occurs. This system has been applied to a continuous round caster, and has effectively regulated the mold bath level fluctuations by adjusting the controlling parameters to optimize the state of operation when the fluctuation occurred.

The expert system proposed in this paper predicts the life-expectancy of spouts. It uses fuzzy inference rules to process input data (steel qualities, actual and predicted casting speeds, type of spout, immersion history of spout) and computes the life-expectancy. This makes sense since:

- uncertain or rapidly changing data, such as the condition of the spout or the casting speed, can be used,
- vague rules, such as "if the steel contains little carbon, then the slag will be very aggressive", are easy to formulate and will work as-is, and
- the scheduling system (Slany et al., 1992) also uses fuzzy values. Therefore, when combining the proposed system with a simlarily constracted scheduling system, a process called defuzzification is delayed until the last decision-making step. Thus, any loss of information is avoided.

In the following, a sample fuzzy computation is explained. As an intermediate step in the life-expectancy computation of the spout, the aggressiveness of the slag is calculated from the chemical contents of the metal. The contents of six chemical elements have to be monitored simultaneously. Their influence can be simulated by a complex non-linear function that normally is represented in several tables consulted by the engineers during their work. In the fuzzy expert system proposed here, these tables can simply be stated as rules describing the influence of the various factors on the outcome. The interpolation is done automatically through the fuzzy inference engine. This system also accommodates for the continuous change in parameter values when slightly different kinds of steel are produced one after the other through the same tundish.

The system performs better than humans in predicting the life-expectancy since it considers more types of influence and reasons with up-to-date information. This is especially important when rescheduling occurs and pondering time for human experts is scarce. For these reasons, the final schedule matches reality closer, avoiding vasted raw materials and production delays as well as increasing qualities.

The interface between the system proposed here and the scheduling system such as the one described by (Slany et al., 1992) works smooth in that all data are available to the scheduling expert system at any time. In case a special situation should arise, such as a broken spout or a breakout of the strand, both systems are informed immediately by the process monitoring system that writes the data into a globally accessible data-base. The scheduling expert system is programmed to ignore all data coming from the expert system proposed in this paper in case of an ambiguous situation. Additionally, the proposed system can signal a sudden change in expected life-time for the current tundish by a special high-priority signal to the scheduling expert system, thus eliciting that in some cases a rescheduling-task is performed by the scheduling expert system. Nevertheless, the information flow is more or less unidirectional, from the system proposed in this paper to the scheduling system.

RESULTS AND OUTLOOK

In this case, a fuzzy expert system is the best choice regarding easiness of implementation, knowledge formulation, and in keeping the knowledge-base up-to-date. Tuning the system is possible since a lot of test data were collected previously during regular production. Further, the problem is small, well-defined, and stable. This is also the reason for not incorporating the function performed by the system into the scheduling system mentioned. The interplay between these two systems can be seen as the study of a real-world application of distributed knowledge-based systems.

The idea to use a fuzzy expert system for this type of problem came after doing a study of expert system technology in the Japanese steel industry (Slany, 1991) during a two-year sabbatical at the University of Tokyo.

We are planning to extend the design of the system proposed in this paper to allow it to learn according to the feedback from the actual process data. In a similar fashion, (Kominami et al., 1990) have used a neural network in their Yawata Works plant to forecast the breakout of the strand in continuous casters. We are currently studying the combination of our technique based on fuzzy logic with the learning capability given by neural networks, genetic algorithm, and case-based reasoning.

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