This paper describes an interactive expert system application for scheduling of resources in continuous manufacturing of a variety of products in a hierarchically distributed control system. The product orders are received by the scheduling application from an upper level in the hierarchy whereas the dynamics of scheduling arise from nonideal operation of production equipment which affect the quality and specifications of the actual product. Furthermore, changing product specifications require constant modification of the production equipment in real time which imposes limitations on the sequencing of products. The information on a scheduled production run not meeting the specification is transmitted to the expert system application from lower level systems in the hierarchy, which perform monitoring and control of the production equipment. The technique is illustrated with an application in steel production.

The steel manufacturing consists of making pig iron from ore, producing molten steel in basic oxygen furnace, followed by casting into slabs, blooms or billets. The scheduling problem arises in various steps of the steel making process, including the basic oxygen furnace, ladle refining, continuous casting, annealing, cold rolling and finishing. The scheduling problem is defined as determination of what resources to allocate or assign to each product and its accompanying process at what time. These allocations must satisfy the equipment constraints which are generally stated in the form of "rules". The rules are derived from operational experience with the equipment and change often as more experience is gathered. The goal then is to find feasible schedules which meet the constraints and provide a flexibility to a human expert to select one among multiple schedules when available.

The system must also allow the relaxation of certain rule constraints to attain a feasible schedule when none is available and to process an expedited/special order at the risk of violating one or more constraints.

Since the system is rule based, the complexity of the problem is based on the number of rules at each point of production. The continuous caster presents the largest number of rules or constraints. It may vary from 25 to 100 depending upon the definition of rules. Many rules are guidelines or soft constraints, which make their mathematical or algorithmic interpretation difficult. These rules come from intuitive experience gained from the equipment by the operators.

In this paper we will illustrate our rule based scheduling technique on a continuous caster. A rule subset of a dozen rules and a weekly order subset of 30 to 40 products, with varying carbon content, widths and alloy types will be selected. The time slots to be filled may be selectively blocked due to scheduled or unscheduled downtimes. The rule subset consists of hard as well as soft or fuzzy heuristics constraints. In normal operation the human schedulers receive the input list of orders from the ordering department office and try to find a feasible sequence of production of the orders in a table. The scheduler, first blanks out portions of the table where the production equipment, in this case the caster, is known to be out of service. Next, the orders are first grouped and sequenced in a manner to meet the basic hard constraints or rules. In the second round of analysis the secondary constraints are used in attempts to satisfy the production requirements. In the last round all the soft constraints such as those with "should" or "try" are used to complete the production schedule. When sequencing is found infeasible, the operator is allowed to ease the constraints to see whether orders can be scheduled with some penalty for violating the constraints. In addition the scheduler has several options to be stopped for reseeding, removing some orders and manually replacing orders to preempt the computer solution and reorder the priorities.

The changing nature of the rules necessitates either a familiar programming environment if a totally programmerless system is not possible. Because of the nature of the problem a fully object oriented program is also difficult to design. Also the plant environment requires that the scheduling system be made to run on conventional computer systems available at the supervisory level in the plant CIM hierarchy. With these restrictions and based on our past experiences we formulated the problem using the IBM Knowledge Tool which provides the execution speed of a compiled language, efficiency of RETE algorithms, PL/I statements to provide procedural language for the sequencing logic and graphic interface required for user interaction as well as the rule formulation in PL/I like structure.

The paper will discuss the results of the knowledge based scheduler, advantages of the technique and further extensions of this approach to the general problem of scheduling using combined machine/operator heuristics.