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# Training and Operations Integrated Calendar Scheduler - TROPICS

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### Abstract

TROPICS is a rule-based scheduling system that optimizes the training experience for students in a power (note this change should be everywhere, ie. Not reactor) plant environment. The problem is complicated by the condition that plant resources and users' time must be simultaneously scheduled to make best use of both. The training facility is highly constrained in how it is used, and, as in many similar environments, subject to dynamic change with little or no advance notice. The flexibility required extends to changes resulting from students' actions such as absences. Even though the problem is highly constrained by plant usage and student objectives, the large number of possible schedules is a concern. TROPICS employs a control strategy for rule firing to prune the possibility tree and avoid combinatorial explosion. The application has been in use since 1996, first as a prototype for testing and then in production. Training Coordinators have a philosophical aspect to teaching students that has made the rule-based approach much more verifiable and satisfying to the domain experts than other forms of capturing expertise.

## Task Description

Power plant operator certification requires that students undergo a lengthy training regime at several schools. The curriculum comprises numerous classroom and hands-on training activities. The final phase of training is entirely hands-on at a single facility, where each student is required to successfully complete several hundred tasks to receive certification. Completion of this portion of the certification process requires approximately three months of training and is subject to numerous prerequisites and sequencing constraints. Each student is assigned to one of approximately 20 different types of certification, each with differing requirements. Several hundred students pursue certification simultaneously. Students are trained together as a class, following a prescribed curricula. Several different classes at different progress levels use the training facility at the same time not unlike a university setting.

Training takes place at different locations, known as "watchstations" within the facility. Some training requirements can be satisfied by the use of a plant simulator. Plant Training Programs (PTP) are specific sequences of plant evolutions designed to train students for various operating conditions of the plant. To minimize wear on plant components, it is desirable to perform only the number of plant evolutions necessary to allow students to complete their training requirements. Thus, making efficient use of plant resources is a goal of the TROPICS system.

The primary objective of the certification program is to maintain a steady output of qualified operators. This requires efficient scheduling of training activities to meet certification deadlines. The scheduling of training activities is further complicated by planned and unplanned facility maintenance shutdowns.

Specialists are assigned the task of creating and maintaining training schedules manually as one of many other responsibilities. These individuals retain this responsibility for a relatively short period of time, less than one year. While they are familiar with the operator qualification process, they are initially inexperienced in creating training schedules. A substantial amount of practice is needed to be able to produce good quality schedules. The planned, frequent turnover of personnel makes the risk of losing scheduling expertise high.

It is desirable to avoid rescheduling a student for incomplete training by maximizing the probability of success the first time through. For example, training activities scheduled too close together do not allow students a sufficient amount of time for preparation.

Repeated training reduces the overall training capacity of the facility. The training capacity of the facility is constrained by the prescribed order of plant evolutions. The condition of plant components and maintenance adds dynamic constraints to an already highly constrained resource.

Prior to the start of a new training class, the Training Coordinator (TC) creates an initial schedule containing a sufficient number of Plant Training Programs so that it is expected that all students can complete their training requirements by the specified date. This schedule accommodates known plant maintenance shutdowns. Once the initial plant schedule has been created for a class, individual student schedules are created with the goal of maximizing the quality of training. When training actually begins, unanticipated events such as student illness and unplanned maintenance may require the schedule to be adjusted up to several times a day.

Over about a ten-year period, several small procedural applications have been written to reduce the burden of the Training Coordinator in setting up training schedules. It had long been recognized that quality of training schedules had to be more uniform over the various TCs. Most of these applications were "book-keeping" tools that helped the TC track requirements while training schedules were being generated. Some of the applications were able to generate initial schedules, which then had to be manually adjusted to meet minimum training quality criteria. None of these applications was robust enough to automate many of the decision making processes required to set up quality training schedules. Also, none of the applications was able to automatically reschedule tasks.

In the Training and Operations Integrated Calendar and Scheduler (TROPICS), a heuristic method was selected because of the size and highly constrained nature of the scheduling problem. Similar problems had been successfully solved using rule-based expert systems (Yang and Ignizio, 1987, Jones, 1989, Levine and Pomerol, 1990). Enumerative scheduling algorithms (Blazewicz et al, 1994) that provide a single exact solution to a scheduling problem are impractical for this application as there is no guarantee that a feasible solution exists or can be reached in the time frame required. In many actual situations, training schedules must be reworked periodically due to changes in scheduling resources. In these cases, the expense and risk of using an enumerative method does not justify the optimal solution. Surveys of heuristic methods (Noronha and Sarma, 1989, Liebowitz, Lightfoot and Dent, 1991, Liebowitz and Lightfoot 1987) suggest that this technology can yield feasible solutions to this training scheduling problem in the required time.

TROPICS is a rule-based system that automatically schedules the required practical training to become a qualified operator. The primary objective of the system is to emulate the collective excellence of many Training Coordinators. TROPICS was designed to retain corporate knowledge in an environment where there is rapid turnover of Training Coordinators. In this application all students, in all classes, are certified by a prescribed date with a uniformly high quality training experience. The system seeks to minimize operation at particular plant conditions, and minimize the frequency with which students must be rescheduled for the same training activities. Finally, TROPICS reduces the administrative burden on schedulers, freeing them for other responsibilities.

A rule-based solution was chosen as it closely models the process used to manually schedule training and provides a natural form for maintaining the scheduling knowledge as new heuristics are developed in response to changes in the facility and training environments. An intelligent system provides the additional capabilities of generating solutions to unanticipated situations and allows trainers and facility planners to investigate alternative scheduling scenarios.

## Application Description

It was realized that a single expert system would become overly complex given the variety of tasks that must be performed to create acceptable schedules. TROPICS is therefore composed of a collection of integrated modules.

There are two basic types of schedules that TROPICS must generate. The controlling data are the class demographics, student requirements and resource availability. The first stage in the process, the PTP Scheduler, creates the training facility schedule. The second stage, the Initial Watchbill Generator, superimposes a student training schedule on the facility schedule. Later stages provide capabilities for updating and improving schedule quality in response to changes in the training environment.

The major components of TROPICS are:

- **Plant Training Program (PTP) Scheduler** – a plant scheduling module that computes the number and sequence of required plant training programs. It then maps these PTPs onto days that are available for training.
- **Initial Watchbill Generator** – a student scheduling module that assigns individual students to watchstations for the specified PTPs.
- **Expander** – a module that assigns PTPs to unscheduled time in the schedule so as to provide improvement in student training quality.
- **Rescheduler** – a module that receives updated student training information and reschedules students to

complete training activities as required.

**PTP Scheduler**

The PTP scheduler is the first step performed by this application when a training session begins. The objective is to schedule sufficient plant activities to meet the training requirements of a class.

The PTP scheduler accounts for numerous factors that constrain the scheduling of a class previously mentioned. Typically, there are periods of time when the training facility is not available for student training due to maintenance and testing activities. There are other instances when only certain PTPs can be scheduled due to plant operating restrictions.

There are factors that affect training quality. Experience has shown that when students are trained too rapidly, there is an increased probability that they will not complete all their training requirements within the assigned time. Additional training time must then be scheduled for them to complete their requirements and this ultimately reduces the training capacity of the plant. TROPICS employs a "training curve" for a given class, which is used to automatically regulate the pace of training. It has been observed that students will be trained most effectively if the pace of training is initially slower and then, as facility familiarity increases, the training rate is accelerated. Figure 1 shows the user interface for this example where the training curve is adjusted by moving the slider bars to the desired position. An alternative training strategy is shown in Figure 2 (need to reverse figure names) where the rate of training is faster in the early stages of training and slower at the end. Different training facilities employ different teaching philosophies. Teaching philosophies are modeled by the training curve. The advantage of this training curve is the flexibility to accommodate different training strategies.

**Figure 21. Training Curve for Normal Training Progression**

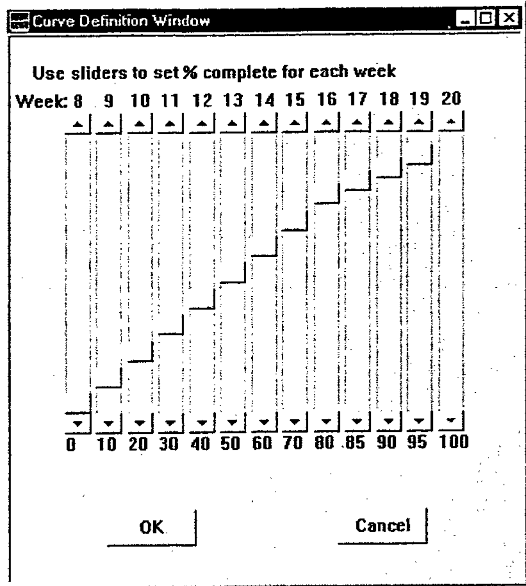
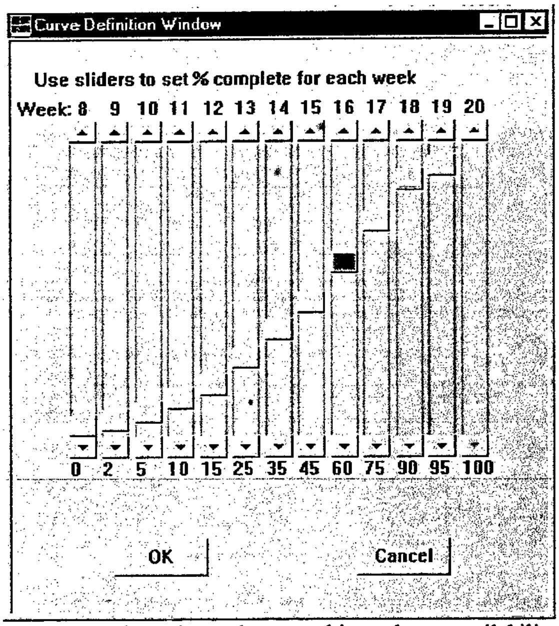



**Figure 12. Training Curve for Accelerated Training Progression**




Given the class demographic, plant availability schedule, and the training curve, the PTP scheduler constructs a complete plant schedule. The PTP Scheduler determines the types, computes the quantities, and is given a heuristic ordering of the PTPs required. The system then determines if all PTPs can be scheduled by the required end date. If not, the PTP Scheduler will compress earlier class schedules to make available more training resources for the current class.

**Initial Watchbill Generator**

The objective of the Initial Watchbill Generator (IWG) is to assign students to watchstations given the established PTP schedule. This is done in a way to maximize the quality of each student's training experience while assuring that the required constraints are satisfied. The watchstanding schedule is created simultaneously for all students in a class. There are occasions when a student requires an individualized training program and needs to be scheduled independently from a training class. TROPICS has the ability to schedule individual students in those cases.

A PTP schedule does not take into account the required sequencing of training requirements that must occur for individual students. In order to satisfy the required training sequence for each individual student, care must be taken in assigning the training activities to avoid infeasibilities for the student.

The IWG begins by organizing the training requirements into a series of scheduling steps. The steps are arranged in descending order by those students with the largest number of requirements and those watchstations with the highest demands. The steps are then scheduled in this defined order. If a step is unable to satisfy student requirements, a tightly controlled variant of musical chairs tries to rearrange the existing schedule to accommodate the needed requirement.

Each scheduling step assigns a specific group of students to specific watchstations using two filters. The filters select the specific student-watchstation combination that meets the scheduling restrictions. The filters also assure that as many desirability constraints as possible are satisfied.

The student filter finds the best student for a given time and watchstation. Similarly, the watch filter finds the best time and watchstation for a given student. The training periods are processed sequentially and, based on the student filter, assignments are made. The system detects when a critical point is reached in a watchstation's availability. Then the watchstation filter is employed for the remaining students.

Both filters employ student evaluation criteria, which are broken down into two groups: constraints and desires. Constraints prohibit choosing students for some particular assignment that violates training policy. For example, certain watchstations cannot be scheduled for the same student twice in one day. TROPICS seeks to satisfy as many desires as possible to obtain the highest possible schedule quality. For example, optimize the amount of time between training assignments. The desires are initially ordered according their importance. As the schedule gets tighter, the desires become less controlling.

The filtering methods are easily adapted to accommodate different training strategies and constraints. Each quality measure is assigned a modifiable degree of importance. Additional constraints are easily added. This allows the capabilities of students within a class to be considered by means of constraints. In this manner, the rate of training can be adjusted for individuals within the scheduling restrictions for a given class.

An advantage of this method of scheduling is that it is opportunistic and dynamic and will increase the probability of obtaining a feasible schedule. That is, after some scheduling has taken place, the system may detect different resource-student situations that will cause it to adapt to a more desirable scheduling sequence. In addition, this automated method of student scheduling produces schedules of consistent quality. By contrast, the manual method produces schedules of widely varying quality.

**Expander**

There are occasions when the facility remains available even after all required activities have been scheduled. The facility operates continuously and any excess, unscheduled time is distributed to the training classes for their use. This affords students the opportunity to obtain additional experience beyond what is required. The additional experience improves the quality of student training and reduces the students' failure rate. Prior to the deployment of TROPICS, this additional time was manually distributed in an ad hoc manner. The system provides an automated means to optimize the use of this additional training time based on objective criteria for improving training quality. Because of the dynamic nature of plant operations it is desirable to avoid committing the excess training time too far in advance. For example, due to an unplanned plant maintenance shutdown a required training session may have to be postponed and is best rescheduled into the discretionary time. The objective of the Expander is to allocate unassigned training time to provide maximal improvement in training quality using a "just-in-time" philosophy.

The Expander, initiated by the user, is provided with a time interval to examine. If unscheduled training sessions are present, the Expander will evaluate one or more objective criteria that measures training quality for each class. For example, the number of students having two consecutive training sessions in a day is a measure of poor training quality. The class with the largest number of students having consecutive training sessions will be assigned the first unscheduled training period. The class with the next largest number of students with consecutive training sessions will be given the next unscheduled training period. This process continues until either all unscheduled time has been assigned or there are no days with students having consecutive training sessions. If unscheduled time remains, then this time is divided evenly between the classes in training during the given time interval. Once all unscheduled time has been assigned to the training classes, the entire time interval is rescheduled to take advantage of the additional training time using the methods previously described.

**Update and Rescheduling**

The objective of the Rescheduler module is to reassign training requirements that were not completed due to lack of student proficiency or facility unavailability.

TROPICS is a data-driven system that periodically receives updated training information from an external database. It then automatically notes the changes as events. These events trigger the system to reevaluate the schedule based on the new information and reschedules as necessary. This system readjusts its selection criteria based on the most current student needs and the availability of remaining resources using the methods described above.

TROPICS provides the ability for users to make changes to the schedule manually through a graphical user interface. Such changes are made by trainers to reflect information that is not contained in the external student training database. For example, a trainer may wish to provide a poorly performing student with more than the required minimum time between training activities so that the student may receive remedial instruction. An important feature of TROPICS is that trainers are only allowed to make changes that are consistent with the scheduling requirements. This is accomplished by presenting the trainer with a filtered list of only those students who satisfy the constraints for a particular training activity.

## Uses of AI Technology

Scheduling is one case of the classic packing problem. It shares an important aspect with that problem in that it looks simple and experts appear to do it with ease. TROPICS is clearly an implementation of the packing problem, first building a training *container* and then filling it in the most expedient manner. There are pitfalls in designing this type of application. In the process of building a system that emulates the packing expertise it is attractive to construct a system incrementally, adding domain knowledge bit by bit. This is an enticing but unproductive approach in an inherently complex problem. It was proven in the case of TROPICS to be far more effective to approach the problem with full knowledge of all constraints and subtleties at the onset. In this way competing constraints can be observed as the system is constructed.

TROPICS depends on the use of a fast pattern matching data driven inference engine. As information regarding changing assets and requirements is fed into TROPICS, the rule-based shell opportunistically selects the appropriate knowledge to be applied in creating or modifying the training schedules and resource requirements. The value of this is that domain experts can easily identify and verify the use of their knowledge in the application.

The inference engine used in TROPICS is Art*Enterprise from Mindbox Corporation. The tool also supports rule-based knowledge as well as object representation with inheritance. The tool selects the most appropriate rule manifested by the dynamic situation and places it on an agenda for activation. Key aspects of scheduling are implemented by means of controls that allow agenda ordering according to established practices. In this particular scheduling domain established practices mix rote procedures and heuristics. This is a difficult mix in scheduling and TROPICS keeps these two process types separate.

While rule-based systems are generally considered to be brittle (having no logic basis outside the prescribed, encoded knowledge), the ability to navigate a deterministic, verifiable path has been the key to success in TROPICS. It has provided the ability to explain *why* a solution is chosen, enabling accountability back to the experts.

Another potential difficulty of rule-based deduction is the combinatorial explosion at various stages of rule selection. In TROPICS, constraint checking reduces the potential search space by pruning fruitless lines of deductive analysis at several stages in schedule development. The deductive process is divided into several stages to enable evaluation criteria to proposed scheduling choices. This allows the system to progress towards the goal, eliminating nonproductive paths, optimizing resource allocation and scheduling quality. By separating experts' scheduling techniques from the resources to be scheduled, TROPICS has demonstrated flexibility in the face of changing environments and application details.

TROPICS imposes heuristic procedural knowledge on the rule firing order to control the direction of the inference engine. This technique ensures that aspects relating to limited resources and varying training requirements are the main considerations in prioritizing scheduling tasks. Operations research techniques, such as linear programming, for the final selection of student assignments were considered.

TROPICS is integrated with two databases. The first is a database containing demographics and training requirements for each type of student in a class. The second is the database into which the final scheduling solution is stored and reviewed.

Art*Enterprise was chosen for a number of reasons:

1. The tool is in widespread use in our AI development environment and as such, the developers were familiar with the programming syntax and knowledge processing methods.
2. Proven techniques of agenda control (rules about rules) made for an easily controllable search path.
3. An integrated editor and data access tools enabled easy development and testing.

## Application Use and Payoff

TROPICS has been deployed at a single training facility since 1996. Five training coordinators who each schedule six training classes annually are using the application. Once a training class begins, complete schedules are updated three or four times per class, on average. This represents an annual manpower saving of approximately 300 hour per power plant. In addition to this savings, TROPICS has improved the quality and consistency of schedules between training coordinators by generating schedules that adhere to best historical principles and practices of training scheduling experts. Prior to the deployment of TROPICS, complete schedules were rarely updated. Rather, schedules were updated incrementally for the next few days or weeks as needed which resulted in suboptimized schedules over the whole training cycle.

TROPICS is also used by resource planners to project the feasibility of implementing facility cost saving measures that will result in the reduction of available training time. TROPICS will be used to determine facility operating schedules that will maximize training throughput without jeopardizing quality.

## Application Development and Deployment

Throughout application development, standard software development life cycle methods and knowledge engineering techniques were employed. Over time, changes in throughput requirements and plant operating conditions resulted in the application of different heuristics to arrive at acceptable training schedules. Considerable time was spent interviewing experienced training personnel who had observed a wide variety of training scenarios. TROPICS was designed to adapt to these different training scenarios.

The PTP scheduling method was developed using a spreadsheet prototype where several models of increasing complexity were constructed. At each stage, scheduling experts performed blind comparisons between manually generated and automatically generated schedules until the automated method produced schedules of acceptable quality. Once the PTP Scheduler was fully developed, planners used it for resource scheduling while the watch scheduling modules were developed. A similar development method was employed for the IWG with the addition of specific metrics that could be used to make objective evaluations of schedule quality.

The development team was comprised of two software engineers, one mathematician, two domain experts, and one project manager. No one worked full time on the development project which spanned ? years. A testing team, consisting of developers and customers, expended additional effort.

The first year of the project was spent researching scheduling methods (Morton and Pentico, 1993 and Zweben and Fox, 1994), expert knowledge acquisition, and designing the software architecture. The major development phases (PTP, IWG) were accomplished in the next three years. As each phase was completed, a prototype was deployed to the user community for testing and evaluation. Since deployment, effort has focused on delivering refinements, enhancements and a platform conversion to a windows-aqbased environment.

Successful deployment of any application requires someone from the user community to support and champion the effort.

## Maintenance

TROPICS was designed anticipating the need for deployment at several additional training facilities with different plant configurations. To that end, there was a conscious effort to employ object-oriented design and to segregate facility-specific knowledge. A rule-based approach facilitates updating training knowledge as new heuristics emerge in response to changes in the operating environment. One of the primary goals of TROPICS was to retain existing training expertise. Therefore, only incremental changes to domain knowledge are anticipated over time. With any training formalism different training philosophies must be accommodated. The user-adjustable "training curve" provides this flexibility.

Maintenance is performed by an offsite subcontractor based on a monthly budget. Each month, maintenance work is prioritized based on user identified needs. An update is provided each month or more frequently as required.

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