PEER REVIEWED

A paper production scheduling system using an expert system

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ABSTRACT

The authors describe a paper production scheduling system for a millwide system using an expert system method. The person responsible for preparing the monthly and weekly production schedules uses an engineering work station employing an expert system function and an assist computer automated drafting system. The procedure simplifies the previous complex and lengthy arranging of more than 200 products in a giant matrix involving ten production lines.

Application:

A computerized system eliminates the need for troublesome manual alterations to a planning schedule and allows easy management of many scheduling items.

With the evolution of new and more advanced technology, companies in the paper industry have tried to introduce millwide systems to automate information systems in all areas of plant production. Beginning in 1980, the authors' company introduced several large computer systems for its mill in Tomakomai, Hokkaido, Japan. The chronology of the development of the system was the following:

- Quality information system:1980
- Energy management system: 1982
- Pulp production information system: 1984
- Paper production and management system: 1988.

In January 1989, the final step in constructing the framework for the mill information system was a joint effort with Toshiba Corp. to develop a scheduling system for production of paper using expert system technology. This paper will outline the paper production scheduling system and discuss its effects.

TOMAKOMAI MILL

The Tomakomai mill has been producing pulp and paper products since 1910. Modernization of the mill with current technology and equipment has been a continuing process with each passing era. Supplying approximately 30% of the newsprint consumed domestically, the mill is one of the largest newsprint paper production mills in Japan. It has seven large paper machines for newsprint and three medium-sized paper machines for printing paper. Annual production exceeds one million metric tons. The fiber necessary to feed these machines comes from more than 10 different pulp production lines producing 18 pulp types consisting of kraft pulp (KP), groundwood pulp (GP), thermomechanical pulp (TMP), refiner groundwood pulp (RGP), pressurized stone groundwood pulp (PGW), and deinked pulp from various bleaching systems and fiber species. The combinations and permutations of pulp characteristics available are therefore enormous. Compounding the complexity of production planning are the more than 200 different production runs monthly. In practice, seven or eight pulp types from those mentioned above are blended with chemical additives and dyes to produce the required quality for each specific product.

The Tomakomai mill consumes approximately 250 MW/h of electric power and 950 tons/h of steam from six steam boilers, 13 turbine generators, and 19 hydraulic turbines on the site. An electric power company supplies the remaining power. Continuous efforts are necessary to control these complex plant operations.

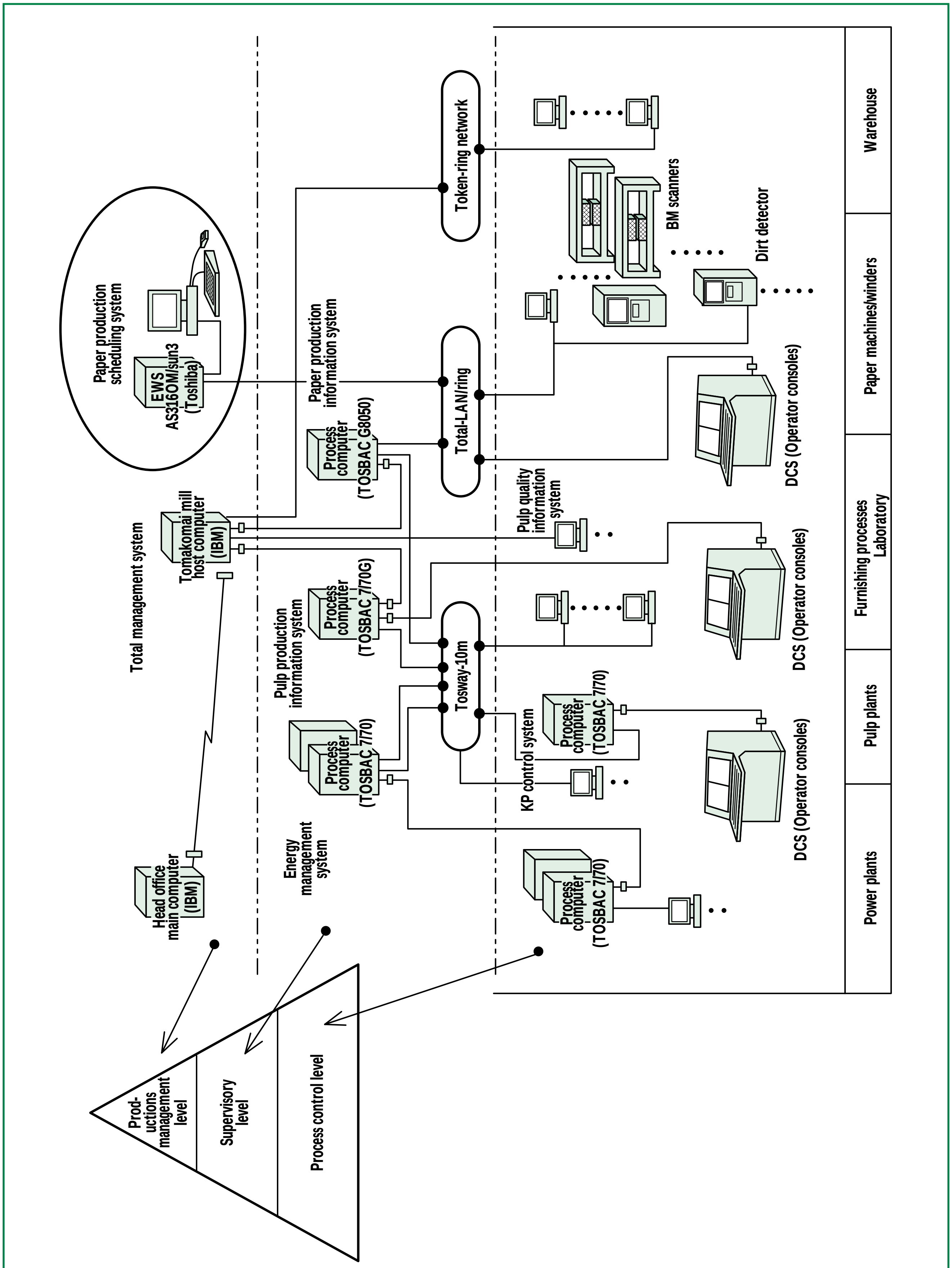
TOMAKOMAI MILLWIDE SYSTEM

Development of a computer information system for all aspects of operation a millwide system (MWS) was necessary to insure product quality while balancing complex operational considerations such as pulp and paper production and power balances. A MWS consisting of seven unique systems split into three layers evolved. The MWS uses nine process computers and approximately 80 CRT terminals as **Fig. 1** shows. The paper production scheduling system occurs at the production management level using an engineering work station (EWS) terminal. The paper production schedule developed under this system goes to the next layer consisting of a paper production information system, pulp production information system, and an energy management system. All departments use the schedule information to plan a more detailed operation schedule for each pulp and energy plant.

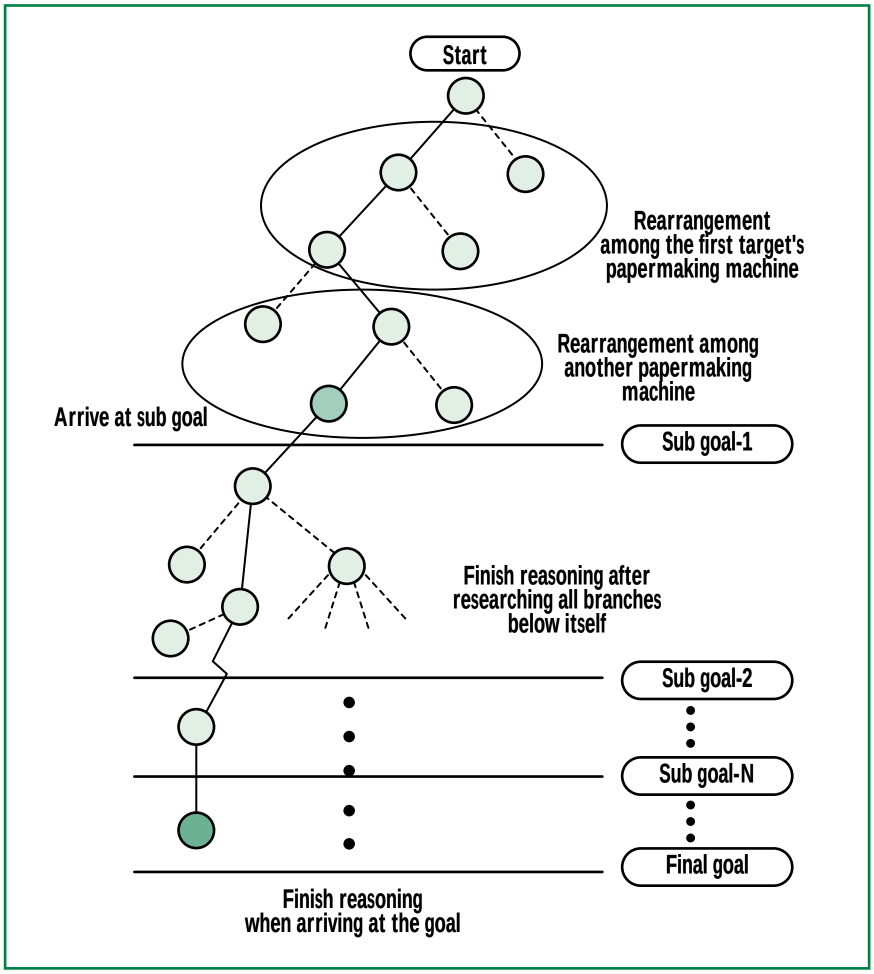
PAPER PRODUCTION SCHEDULING SYSTEM OUTLINE

Purpose

The paper production schedule is the mill management's basic plan. The mill administration generates two kinds of production scheduling: monthly and weekly. Papermaking schedules should minimize production costs while maintaining paper quality under the constraints imposed by pulp



1. Millwide system for Tomakomai mill



2. Flow of the rearrangement reasoning process

Hardware:
Computer : Toshiba EWS-AS3 160M (OEM computer of Sun3 EWS of Sun Microsystems Co.)

Main memory capacity : 8 Mbytes
Outer memory capacity : 130 Mbytes doubled

Calculation speed : 2 Mips (the fastest engineering work station available in 1987)

Software:
Operating system: UNIX
System development language: C
Expert shell tool: Toshiba AS-IREX

I. Hardware and software

production, energy supply, and transportation capability. In addition, negotiation and agreement between the various internal and external sections of the mill must occur within a limited time. A considerable amount of expert and specialized knowledge is therefore necessary to create the paper production schedule. Following are the key difficulties encountered when creating the paper production schedule:

- The large number of pulp types (18 or more)
- The large number of different paper runs (approximately 200 or more for the monthly schedule)
- The large number of products that are mutually incompatible in the order of production requiring separation during production within the papermaking plants.

Before development of the new paper production scheduling system, manual work required two or three people two or three days to complete a single schedule. The greatest difficulties involved the repetition of cumbersome and complicated calculations for pulp usage and energy consumption by manual batch work using office computers. These results required organization into a workable production schedule consistent with the limitations and restrictions concerning product quality and process capability.

The goal was to develop a computer system that could rapidly and effectively create a paper production schedule. Such a system would reduce the labor and time necessary for the task while increasing the quality of the schedule plan.

Monthly and weekly paper production schedules

Planning for the monthly paper production schedule occurs near the end of each month. This schedule plays an important role in establishing the guidelines for production during the next month for each plant in the mill. Pulp usage and electric power consumption is calculated at 30-min intervals for the entire following month.

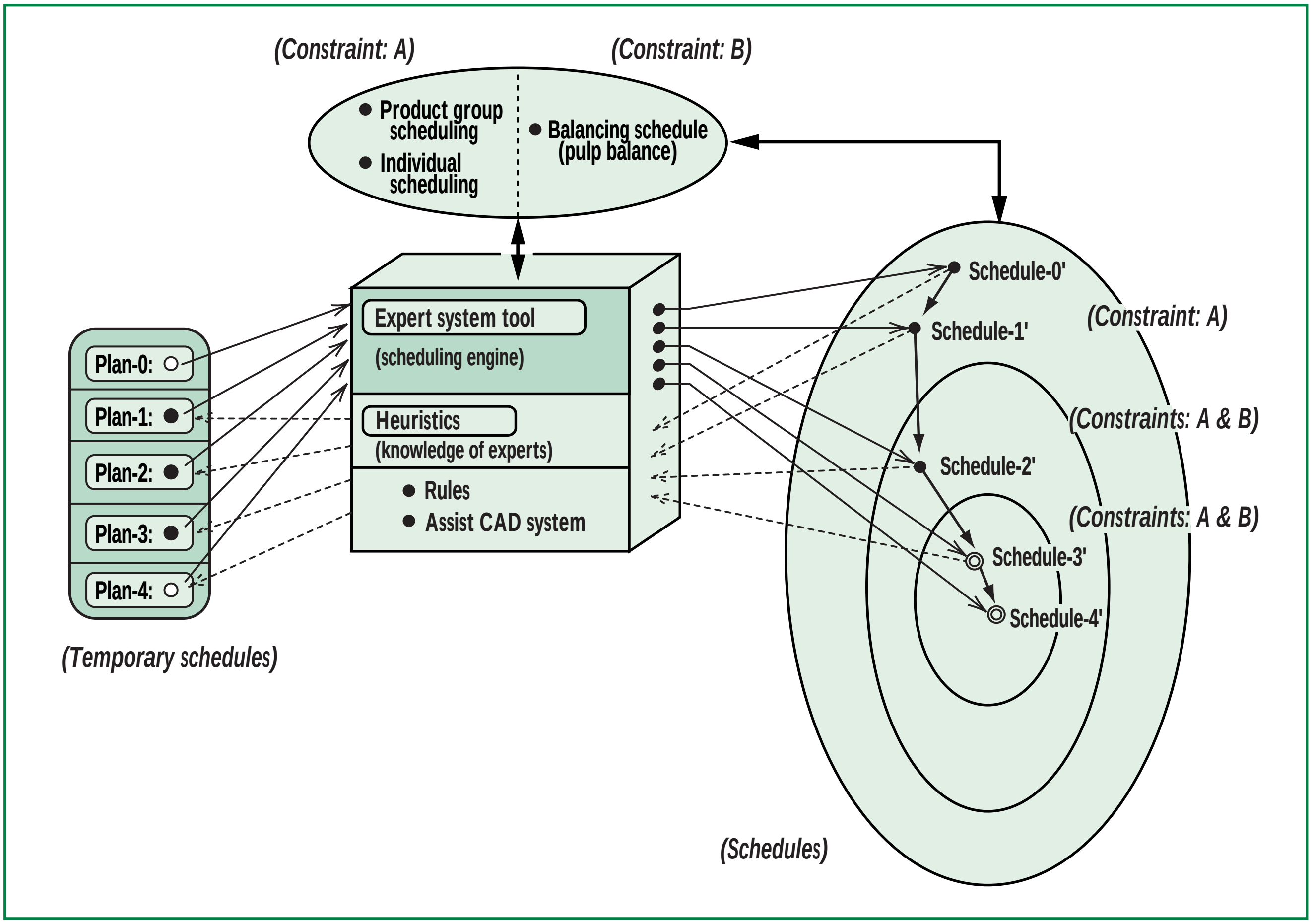
The weekly paper production schedule typically covers eight days. Near the end of each week, this schedule is created for each plant in the mill using the monthly paper production schedule. In addition, the timing of all papermaking is rechecked to confirm the availability of the necessary pulp supply. Since the weekly schedule can respond better to such conditions as machine running speed, efficiency, paper width, etc., a more accurate determination of pulp usage is possible than with the monthly schedule.

Table I shows the hardware and software for the computer system.

EXPERT SYSTEM FOR PAPER PRODUCTION SCHEDULING

Scheduling challenges

The paper production schedule for this mill is very complex due to the many paper products. Each has different specification constraints. The monthly scheduling requires arranging 200 different paper production batches for ten papermaking plants by



3. Schedule making process

assigning 20 products to each of the ten papermaking plants. Calculation of the possible schedule patterns considering these production combinations and the time required to produce each combination assuming 1 millisecond per schedule shows the complexity. The number of schedule combinations is $(20!)^{10}$ or 7.2×10^{183}. The required time would be the product of this number times 1 millisecond or 2.3×10^{173} years. Obviously the time to construct the optimum monthly schedule without a strategy would consume considerable years.

Displaying heuristic abilities, an experienced staff required only three days using the manual method. Knowledge for the expert system came from a close examination of the details of the process involved in the manual schedule. The flows and techniques to make the computerized paper production schedule took four individuals approximately 9-man months.

Components of the paper production scheduling system

The paper production scheduling system has three sub-functions: product group scheduling, individual scheduling, and balancing (replacing) scheduling. It also has a support system called an assist CAD system and several expert functions as **Table II** shows.

Product group scheduling operation

The product group term signifies the operation that classifies all products into approximately 50 main products. This operation assembles products that are similar in quality and share roughly the same delivery period. Planning a rough product group schedule involves arranging these products in a group to satisfy a set of constraints such as delivery period, amount of demand, and mutual arrangement rules between products.

Individual scheduling operation

This operation assigns individual products into their respective product group arranged by the product group scheduling operation above. The schedule here must also satisfy the constraints imposed by the delivery period, demand, and the mutual rules of arrangement between products.

Balancing scheduling operation

This operation improves the schedule without exceeding the approved volume during the schedule period while balancing the total demands for each kind of pulp and associated energy consumption. Rearranging the order of item production within the limits of the individual scheduling operation above accomplishes this.

Preparing the paper production

	Monthly schedule	Weekly schedule
Product group scheduling expert system	0	-
Individual scheduling expert system	0	-
Balancing scheduling expert system	0	Taken from monthly schedule
Assist CAD system	0	0

II. Functions of the production scheduling system

schedule is more efficient when dividing the work into these three sub-functions. The division provides a reduction in the number of constraints and products considered.

Function of the expert system

Product group and individual scheduling

A form of reasoning (forecasting) was initially used to arrange the order of each production run from the beginning of the month considering all the imposed constraints. Completing a schedule was easy initially because of the low number of products and the simple constraints. Further use of this method began to take longer and longer at the end of the operation due to "back-track reasoning." This required checking the arrangement constraints between the same and different papermaking plants. This gave frequent rearrangements. As a result, a new product group scheduling planning method was adopted using the following criteria:

1. Select a product that is difficult to assign to a group that is not already assigned.
2. Decide the starting time of the product arrangement.
3. Check the limitation on arrangement and calculate the room ratio. The room ratio is the summation of the length of time for arranged products in hours divided by the length of time required for an unarranged product in hours.
4. If the product meets all constraints, schedule the product and go to step 1.
5. If the product does not meet all constraints, search for the product causing bottlenecks.
6. Cancel the arrangement of the product in step 5 and go to step 1.

The smaller the value for the room ratio, the more severe the constraints on the arrangement will be. If the value is less than 1, at least one or more already scheduled products must be repositioned. By using this room ratio arrangement strategy, the products appear randomly arranged in the vacant schedule as if the work did not refer to the papermaking plants and time.

This technique is the most constrained strategy *(1, 2)*. Such a strategy can remarkably decrease the number of rearrangement operations and greatly decrease the time given to reasoning (forecasting). Although the strategy of preferential arrangement of products subject to severe limitations has been done manually in the past, previous calculation skills and the ability to foresee situations that may arise had imposed some limitations in applying this strategy fully. The constraint checks governing product arrangement in a schedule were previously assessed from rules (knowledge) and the expert's own information. Knowledge obtained from the person in charge falls into the rule patterns and information of **Table III**.

A similar operation applies to the individual scheduling operation. It differs as follows:

- The scheduled products are individual products not a product group.
- In examining the arrangement of individual products in a schedule, one must consider the previously arranged limitation of the product group schedule.

Balancing scheduling

The next step after completing the individual scheduling operation is to calculate the pulp and electrical use at 30-min intervals for the duration of the schedule. As the demand and supply are nearly balanced for the Tomakomai mill, the result of the first calculation always exceeds the permitted limitation of pulp and electric usage for some scheduled periods. Modification of the schedule to remove these excessive instances must therefore occur by rearrangement of timing—rearrangement of product position in the schedule that results in different pulp compound rate and electric usage.

We used a general investment method to handle these concerns *(1-3)*. The basic flow of reasoning makes a tentative replacement of possible candidates initially. If problems arise, another assumption is made through the back-track reasoning process. This method is repeated until there are no more problems. **Figure 2** illustrates the reasoning process.

Since difficulties occurred in obtaining a perfect solution for the reasoning time problem, we developed a method to obtain a solution by setting a goal higher than the previous one. Instead of setting the break level of the excess pulp amount to below zero tons initially, the level began below 50 tons initially. We adopted a strategy of breaking the quantities of excess pulp in stages *(1)*. Using this line of reasoning accomplishes the balancing and averaging of the pulp peaks and energy excesses more efficiently.

To handle the large amounts of information to process, individual prob-

KEYWORDS

CAD CAM, expert systems, history, information systems, mills (factories), paper industry, production control, production engineering, scheduling, systems engineering.

lems of each papermaking plant focused on information concerning only that plant. This achieved a reduction of the information necessary to consider anytime. Replacing each product in the same papermaking plant to avoid an explosive combination is necessary, since most products have already been assigned to a particular plant. In addition, limitations occur when dividing the production period of the products. In this way, the number of branch lines of reasoning decreases to a finite number.

The three sub-functions of the expert system—product group scheduling, individual scheduling, and balance scheduling, have approximately 50 rules and several hundred limitations.

Rules:
1. Continuous arrangement rule
2. Before and behind relation rule
3. After constant period arrangement rule
4. Prohibition arrangement rule of same period

Information:

5. Delivery period information
6. Divide prohibition information of product into some lots
7. Before arrangement product information with schedule

III. Rule patterns and information

Continuous arrangement rules
Before and behind relation rules
After constant period arrangement rules
Prohibition arrangement rules of same period
Before arrangement product information
Divide prohibition information of product

IV. Rule maintenance windows

Man and machine interface functions

The man and machine interface (MMI) system involves an advanced function—the assist CAD system. The effectiveness of the MMI relies heavily on the assist CAD system. Approximately 70% of the work required to develop the system was spent introducing this MMI function.

Assist CAD system

As one might expect, the expert system seldom completes a schedule plan that completely satisfies everyone. Fortunately, the assist CAD system can edit the schedule by serving as the MMI function. Data entry and output use a keyboard and mouse connected to the CRT of the computer. This simplifies editing of schedule contents using the assist CAD system only. Supporting systems such as pulp or electric use calculation can function independently. Even the expert system for balancing scheduling can be used.

Rules and their maintenance

Production rules fall into three types:

- The rules concerning the product arrangement require changing when specifications change. Since these rules are modified frequently, special maintenance functions were prepared so users could easily edit the rules. **Table IV** shows the rule maintenance windows.
- Strategic rules that search for rearrangable products in balancing the schedule are added to the system when new arrangement patterns for scheduling are necessary.
- The rules to control the overall operation system are the skeletons of the reasoning strategy.

When changing rules for maintenance, editing and addition of other rules is necessary. This is especially true for the second and third types of rules. They may require advanced knowledge of the expert system.

EVALUATION OF THE SCHEDULE CONTENTS AFTER PLANNING BY THE EXPERT SYSTEM

When using operations research techniques to solve this kind of scheduling problem, only one solution results because sequences decided beforehand are used to solve it. Using the expert system with sufficient calculation time, several solutions for a complex problem that must satisfy most constraints can be obtained. This poses a dilemma—determining the best schedule.

Describing the evaluation functions as only one pattern is difficult due to the existence of multiple goals conflicting with each other. **Figure 3** shows many possible solutions *(4)*. The process of making one schedule using three sub-operations in this system is similar to the image of mountain climbing. The options for consideration gradually narrow until reaching the peak where only one solution can apply. The important point to using the expert system is that there is no guarantee that the solution will always be the optimum one. It is merely the closest to the optimum.

As a result, the expert system retains four possibilities for both the monthly and weekly schedules. Because the system does not have an automatic, quantitative self-evaluation system, human judgement is still necessary. The supervisor must compare the four schedules and select the best. Future use of a fuzzy function to connect the plural goals to one function will be introduced if another scheduling system is created.

USE CONDITIONS AND EFFECT OF INTRODUCTION OF THE SYSTEM

A monthly schedule created by the system has rows indicating the number of papermaking plants and columns showing dates. The schedule notes the product code number, name, and the grade change time *(5)*. Depending on the complexity of each problem and the constraints, the time required to make one monthly schedule takes approximately 40 min for the product group schedule and 1 h for the individual schedule.

Approximately 2–3 hours are necessary for the balancing schedule to rearrange one or two pairs of products. **Table V** compares man power and time required to complete monthly and weekly schedules by the new and old methods.

	Manual method	Computer method
Monthly schedule	2–3 persons 2.5–3 days	1 person 2–3 days
Weekly schedule	2–3 persons 2 days	1 person 1–1.5 days

V. Comparison of manual and computer methods

Although there is generally good acceptance of the expert system schedule, the low frequency of use of the balancing expert system is disappointing. Satisfying all constraints of pulp usage during a reasonable time is difficult considering computer execution speed—only 2 Mips. Instead of using the balancing scheduling expert system, the method currently uses the assist CAD system through the CRT window to rearrange the positions of the products. This occurs after checking pulp, electrical, etc., calculations. This method is more reliable and faster than using the expert system method.

Both the expert system and the manual method create the schedule by almost the same process. The difference occurs when the manual method requires special operations. By removing several excess components of the pulp consumption requirements when rearranging the products, one can predict from experience whether making a schedule without changing some products or the pulp compound rates will be possible. Terms are therefore changed, and uses are attained quickly within allowances.

Unfortunately, changing the situation drastically by introducing such flexible functions in this computer system is difficult. When describing the expert's knowledge as a figure of rules, a limitation for extraction can occur. Expert knowledge is something not easily explained to another person.

CONCLUSION

A computerized paper production scheduling system not only removed the need for troublesome manual alterations following schedule planning but also enabled the management of many unitary scheduling data. The person responsible for schedule preparation can use both the expert system and the assist CAD system to create higher quality and more rapidly produced paper production schedules. Although the present technology of the expert system is still under development, this is an effective new method to resolve those challenges that had proven so difficult by previously developed techniques. **TJ**

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