EXPERT SYSTEMS FOR MULTIPLE USES

BY

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DECLARATION OF ORIGINALITY

This thesis contains no material which has been accepted for the award of any other higher degree or graduate diploma in any tertiary institution and, to the best of my belief, the thesis contains no material previously published by another person, except where due reference is made in the text of the thesis.

Paul Crowther

ABSTRACT

It should be possible to build expert systems which are capable of serving more than one purpose. Experts apply their knowledge in more than one way, for example they diagnose, they administer, they train, they schedule and they design using the expertise they have built up. Likewise it should be possible to build an expert system which can be used for more than a single task. The purpose of this study was to identify a problem domain where this could be done, pick an appropriate development methodology and build such an expert system.

The system which was finally chosen as a candidate for development was the evaporator section of the chemical recovery process at Associated Pulp and Paper Mills pulp mill at Burnie. The system was initially built using knowledge about fault diagnosis but with the aim of using it as part of the operator training process. The third purpose was to optimise the maintenance cycle and hence reduce down times of all or part of the evaporator process by investigating key features at set intervals. Fast prototyping was used for the development of the system with knowledge being obtained via interview with multiple experts, operators' manuals, trouble shooting guides and evaporator log sheets.

The system was developed on a cheap micro-computer based shell. It is operational and is currently being used as a fault diagnosis assistant and for training.

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1 INTRODUCTION

The aim of this study was to investigate the use of a single expert system for multiple purposes. To this end a system was developed for training, fault diagnosis and system preventative maintenance. This system has been installed and tested at the Burnie Mill of Associated Pulp and Paper Mills (APPM).

There were also a number of sub-aims to the study:

- Investigating the feasibility of using multiple as against a single expert in the development of an expert system. There has been considerable debate about this point in expert system development methodologies. The view that will be put forward is that rarely will one person know everything about a problem domain.

- Investigating the feasibility of developing a medium sized expert system on a small scale (personal) system using a cheap commercially available shell. If this is viable it should reduce the traditional costs and risks of introducing expert systems into small and medium scale private enterprise.

In the first part of this thesis the background of the project will be given. This will include an overview of the use of expert system technology in the pulp and paper industry, why the evaporator section was chosen as the setting of the project and an overview of the pulping, chemical recovery and evaporator processes.

The methodology used to develop the system will be discussed. The knowledge engineering techniques used will be stated and a description of how the knowledge base was built and tested will be given.

Results will be presented on how well the system performed in the three areas of usage. These results will then be discused in terms of the systems use in concurrent multiple roles. Finally a discussion on areas for future research and the conclusions reached by this study will be presented.

2 BACKGROUND

2.1 EXPERT SYSTEMS IN THE PULP AND PAPER INDUSTRY

The forest resources industry including pulp and paper manufacturing is one of Tasmania's leading industries, both in terms of revenue and employment. There are firms operating in the State, Associated Pulp and Paper Mills (APPM) being the biggest with three mills located in Burnie, Wesley Vale and Longreach. In the south of the State the biggest employer is Australian Newsprint Mills (ANM).

The use of expert systems in these companies can be described as experimental. The system around which this thesis is based is the only one under development at APPM's Burnie plant and there is a second system under development at ANM. This situation is not confined to the forest based industries. Generally expert system are not used as production systems within Tasmanian industry.

A reason for this situation appears to be the perceived development costs of expert systems in an economy where there is pressure to reduce costs. Early comments on the use of expert systems in the forest based industries reinforce this view (Beaverstock, 1985). It is suggested that large amounts of material resource need to be expended to develop a useful system. Moore (1985) describes the resources necessary to build a serious expert system, which included hardware and software costs in the region of $200,000 and a project team of at least six. The salary bill was estimated to be around $300,000 over a two year period. Moore therefore considered a total of $500,000 as a reasonable cost for the development of an expert system. Beaverstock (1985) supports this view mentioning specialised work stations costing $100,000.

For the purposes of this study the kind of budget mentioned by Moore and Beaverstock was far too big. In the case of APPM an initial system had to be demonstrated as viable and cheap. An earlier study done for the company by BHP was discontinued due to the cost of development being quoted in the region of that suggested by Moore. Since Moore's paper was written software and hardware resource costs for expert systems have dropped dramatically. Lukas and Keyes (1989) state that the era of large stand-alone computers running expert systems is over. Rather there is a trend towards smaller systems which will run on general purpose microcomputers using a relatively cheap commercial shell. This was the approach taken for this project. Personnel costs remained the major financial outlay. From APPM's point of view the domain expert's salary was the only major cost (about $40,000).

It is interesting to note some of Moore's closing comments from 1985 which give an idea of where APPM is placed in relation to expert system development.

> **"When should you start? Maybe you should wait. At this time the technology is young - as computers themselves were 20 years ago - and only certain groups should undertake such projects. The primary benefit for starting now is to get your company onboard the technology, to train your personnel and to prepare the way for widespread implementation. The corporate engineering groups, and those mills with substantial**

> **stand alone computer expertise are the groups who can move ahead with success." (Moore (1985))**

Other mills outside Tasmania have already embraced expert system technology for a variety of tasks, and specialist systems have been built. They appear to be relatively few in number, however. The most ambitious of these is the WEDGE (Wet End Diagnostic GEnius) system (Ritala *et al.*, 1990, Paulapuro *et al.*, 1990) which is a process-analysis system for the wet end process of a paper machine. WEDGE is used to analyse pressure and consistency variations and mechanical vibrations which affect paper quality. Changes in these factors are slow and occur generally as continuous drifts. The system uses expert knowledge to predict when these 'drifts' reach a critical point and maintenance needs to be done. Analysis of past data was used to model the system and this was supplemented by human experts. The resultant model is now run off-line but its long term future is as an on-line system.

A second example is LES (Lathe Expert System) (Massey *et al.*, 1989) which is designed to run on a microcomputer. It gives advice on problems associated with lathe operation and veneer quality in a plywood mill. This was developed to preserve expertise, make expertise available in remote locations and standardise the approach to problem solving. It was also justified as a training tool but its use in this guise was not stated. Multiple experts were used to develop this system which was implemented off-line on an IBM-AT microcomputer.

A final example is given by Metz (1986) in the form of the Recovery Boiler Tutor. This is also an example of a system with multiple uses. Primarily it was designed to train recovery boiler operators to adjust control variables so maximum steam output, minimal emissions and safe furnace operations could be maintained. It is also being used in process operations where it provides expert advice to operators on complex operations such as start up and shut down. This appears to have occurred after its acceptance as a training system.

Other specific examples are much more difficult to find. The literature suggests areas in which the forest based industries could use expert systems. Bouchard *et al.* (1989) for example, suggests seven different areas including trouble shooting, planning and scheduling, process engineering, process operations, quality control, process control and training. Lukas and Keyes (1989) present a similar classification but add that there should be a move to on-line and real-time systems. Few, however, suggest using one expert system for more than one purpose other than making general comments about uses in training. Boettcher and Herb (1986) came closest to suggesting systems should be developed for use in more than one role by suggesting that several expert systems could be interconnected to give process control benefits.

The situation is similar in other industries where most expert systems appear to have a maximum of two uses. For example an expert system being specifically developed for training and production work is hinted at in Gregor *et al.* (1990) where a system was developed to aid students learning taxation law. The system was so well accepted by students it was also decided to market it as an aid to professional tax consultants. It was not made clear if former students continued to use the system after graduation.

In another example, Freeman *et al.* (1990) describes a system for operator guidance of blast furnaces. This system is continuously available (off-line) and is able to accept key data on the furnace operation. The system was presented as a diagnosis expert but its description suggests it was more a process operations system with a diagnosis component. If it were operated at a regular interval it could be regarded as doing both.

2.2 CHOICE OF PROJECT

A number of candidates for an expert system were investigated. These candidates had several features which were evaluated using criteria described by Slagle and Wick (1988) and Bouchard *et al.* (1989). Specifically the following issues were considered: the nature of the task, the availability of an expert and attitudes of users and management to computers and expert systems. Five potential systems were investigated. Two were rejected as being too big and ill-defined, two were discontinued after the development of an initial prototype and the fifth was developed into an operational system.

The Evaporator Diagnoser and Maintainer was selected because it had the most potential for development as an expert system with multiple uses. There was a need for expert advice to be available for trouble shooting of the evaporators on a continual basis. In 1989 it was estimated that $3,000,000 of caustic soda was lost due to the evaporators flashing (boiling over). Secondly knowledge of the evaporator section was part of the career path of at least three strands of operator development. A copy of the proposed career structure is in appendix A. Hence there was a continuing need to train not only new operators but also more senior staff who were looking for promotion. Thirdly the evaporators need periodic maintenance that cannot be predicted using time in service alone. The efficiency of the evaporators declines as deposits build up, therefore a reliable mechanism to optimise the maintenance cycle would be valuable, rather than relying on operators judgement (which tends to be influenced in different ways by different symptoms). Poor performance by the evaporators results in slower caustic soda recovery and hence less wood chips can be processed. Also in an attempt to maintain evaporation rates extra steam is applied which means more coal is needed to generate that steam.

The evaporator section therefore met the requirement of being suitable for development of an expert system for multiple uses. It also met the requirements as a candidate for an expert system development in general terms. There were recognised experts in the area who could articulate their knowledge and were willing to participate in the development of an expert system. There was also some well-written documentation about the area available and the problems were well understood.

There was a demand for the expertise. The turnover of personnel in the section was high and although experienced operators were available not all were skilled in all aspects of the of the evaporator's operation.

The risk for the company was also low. The evaporator system could be developed cheaply on existing hardware using a low cost expert system shell. The cost of a consultant was low because I was supplying knowledge engineering services free of charge. That left the domain expert's time as the major cost to the company. On the other hand the returns to the company were high. If the incidence of flash-over were reduced by 50% the company would save $1,500,00 worth of caustic soda.

2.3 SETTING OF THE PROJECT

2.3.1 OVERVIEW OF THE PULPING PROCESS

The evaporators are part of the chemical recovery process of the chemical pulping operation. The flow of materials through the pulping and recovery system is shown in figure 1.

The chemical pulping operation involves separating wood fibres by dissolving the lignin which cements and binds the soft wood fibres together. This done by cooking wood chips in digesters containing a strong alkaline cooking chemical. Dissolved lignin and spent cooking chemicals are washed from the cooked wood chips by injecting hot water into the bottom of the digester and withdrawing spent cooking chemical and lignin from the top. This mixture is known as spent black liquor.

The washed pulp is then further processed to produce white paper pulp from which fine paper can be made.

The spent black liquor is then processed to recover the cooking chemical. This is done for both environmental and economic reasons (the chemical is very expensive).

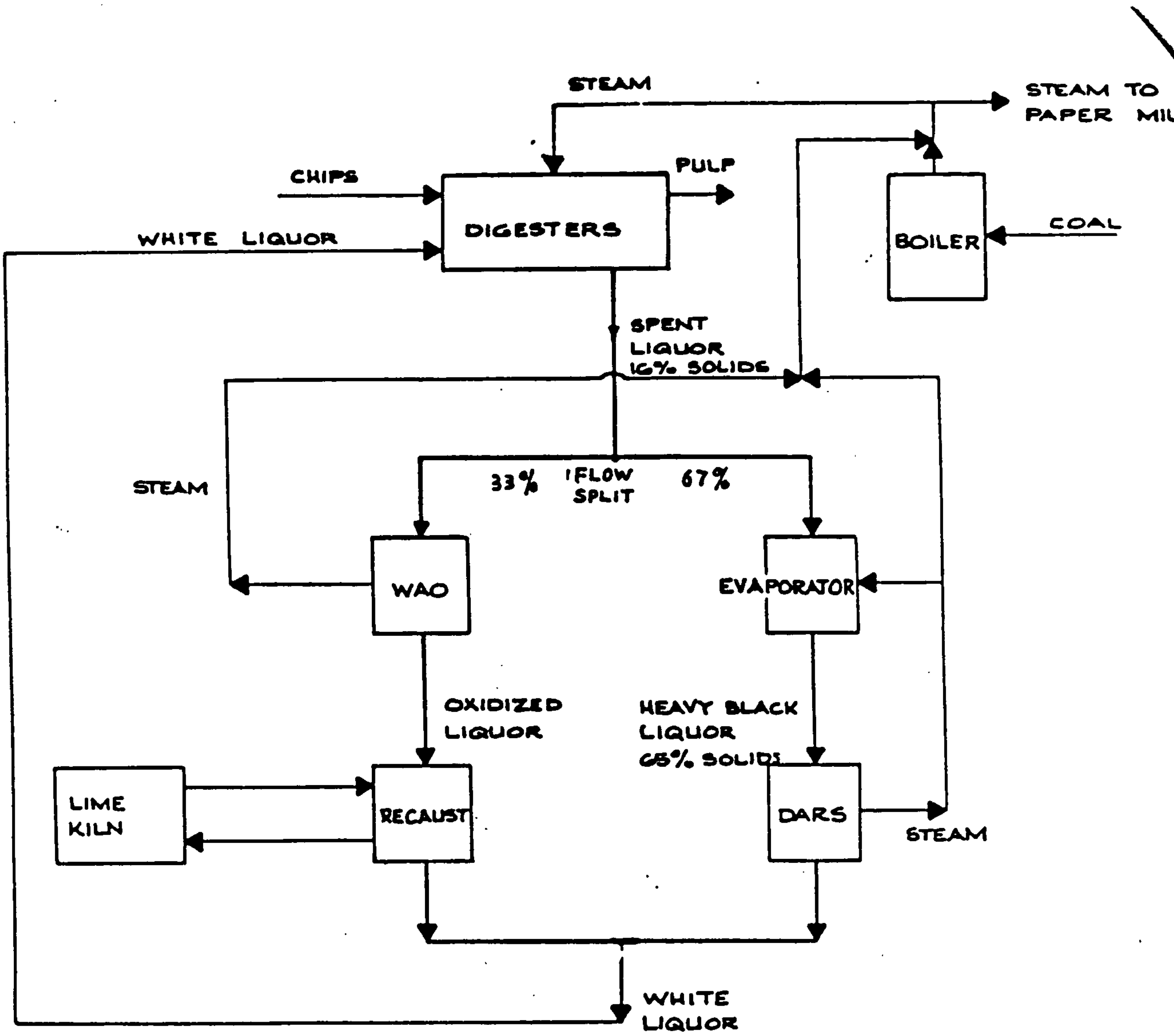

FIGURE 1: PULP MILL RECOVERY INCLUDING WAO

EVAPORATOR TRAINING MANUAL (Associated Pulp and Paper Mills, 1986a)

The spent black liquor has three components : water, sodium compounds and organic material. The organic material is burnt to produce process steam. The sodium compounds are recovered and converted back into white liquor for re-use in the digester. This conversion is done by two processes, Wet Air Oxidation (WAO) and Direct Alkali Recovery System (DARS). The DARS plant is responsible for two thirds of the chemical recovery.

The DARS plant requires the spent black liquor to be at a concentration of 60% to 65% solids. When it leaves the digester it is about 16% solids. If this is not increased, the feed to the DARS furnace is too dilute and efficient combustion is not maintained leading to low rates of conversion to caustic soda and low steam generation. To increase the concentration a large amount of the water needs to be evaporated off. This is the function of the Evaporating Unit around which this study and system are based.

2.3.2 EVAPORATOR OVERVIEW

The evaporating unit consists of three types of evaporator. These are the multiple effect evaporators, finishing pan-calandria system and falling film evaporators. The relationship and liquor flow between the evaporators is shown in figure 2.

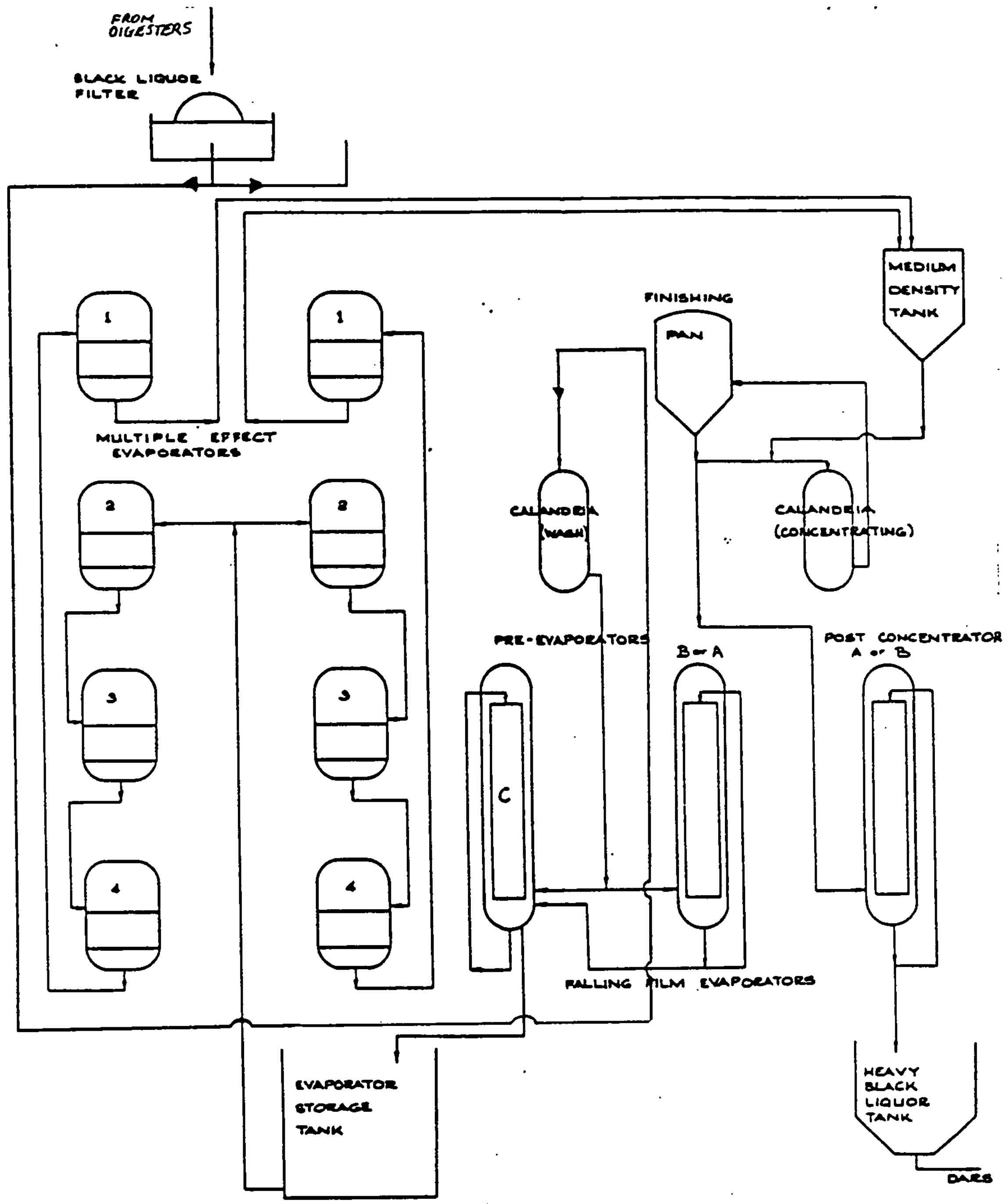

FIGURE 2: LIQUOR FLOW DIAGRAM - EVAPORATORS

EVAPORATOR TRAINING MANUAL (Associated Pulp and Paper Mills, 1986a)

2.3.3 EVAPORATOR PROCESS DESCRIPTION

PRE-EVAPORATORS

Black liquor is initially filtered (by the Black Liquor Filter) and then fed to the pre-evaporators which are of the falling film type. This concentrates the liquor to about 20% solids before it goes to the evaporator storage tank.

MULTIPLE EFFECT EVAPORATOR

Liquor is supplied to the two equivalent sets of multiple effect evaporators from the evaporator storage tank. In these evaporators liquor is concentrated to 42% solids before being sent to the medium density storage tank.

FINISHING PAN CONCENTRATOR

There are two parts to this system one of which is always on a wash cycle with liquor prior to entry into the pre-evaporator. The active part concentrates the liquor to 57%.

POST-CONCENTRATOR

There are three falling film evaporators, vessel A, B and C. C is always a pre-evaporator where as A and B are alternated between being a pre-evaporator and post-concentrator. This is done so the vessel acting as a pre-evaporator can be washed by weak black liquor. The post-concentrator produces heavy black liquor

(65% solids) which is sent to the heavy black liquor storage tank ready for use at the DARS plant.

2.3.4 EQUIPMENT DESCRIPTION

See plates 1, 2 and 3.

MULTIPLE EFFECT EVAPORATORS

Figure 3 shows an effect. It is one of four in each set and there are two sets. Liquor is heated in the calandria, a set of vertical tubes through which the liquor circulates. This is done by applying steam to the tubes where it condenses heating the black liquor in the tubes to a point where it boils. The vapour is then fed to the steam chest of the next effect in the set as the source of steam for further evaporation. Concentrated liquor is withdrawn from the bottom of each effect and sent to the next. Condensate is also withdrawn continuously from the effects. Non-condensible gas may come in with the liquor or steam and is removed from the steam chest through small vent lines to avoid accumulation.

The liquor level in each effect is maintained slightly above the calandria tube sheet to achieve maximum evaporation. This is a manual operation achieved by adjusting liquor flow valves into and out of an effect. Too high or too low a liquor level will result in problems.

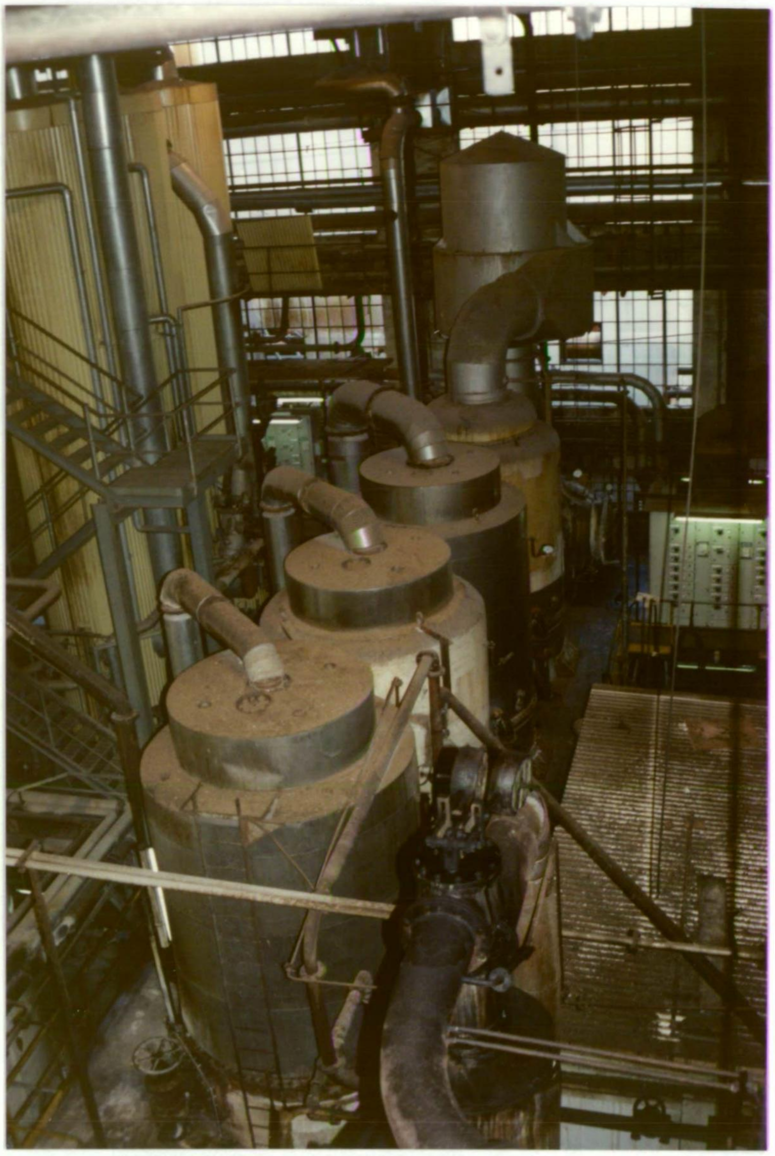

PLATE 1: A general view of the evaporator section looking south from the top of the finishing pan. The four effects of number 2 set of the multiple effect evaporators are in the centre. The device at the centre rear is the cyclone and just visible at its base is the surface condenser. To the left are the falling film evaporators and to the right, the roof of the control room.

PLATE 2: Falling film evaporators (centre rear). Vessel C is the left most of the three. In the foreground are two effects of number 2 set of the multiple effect evaporators.

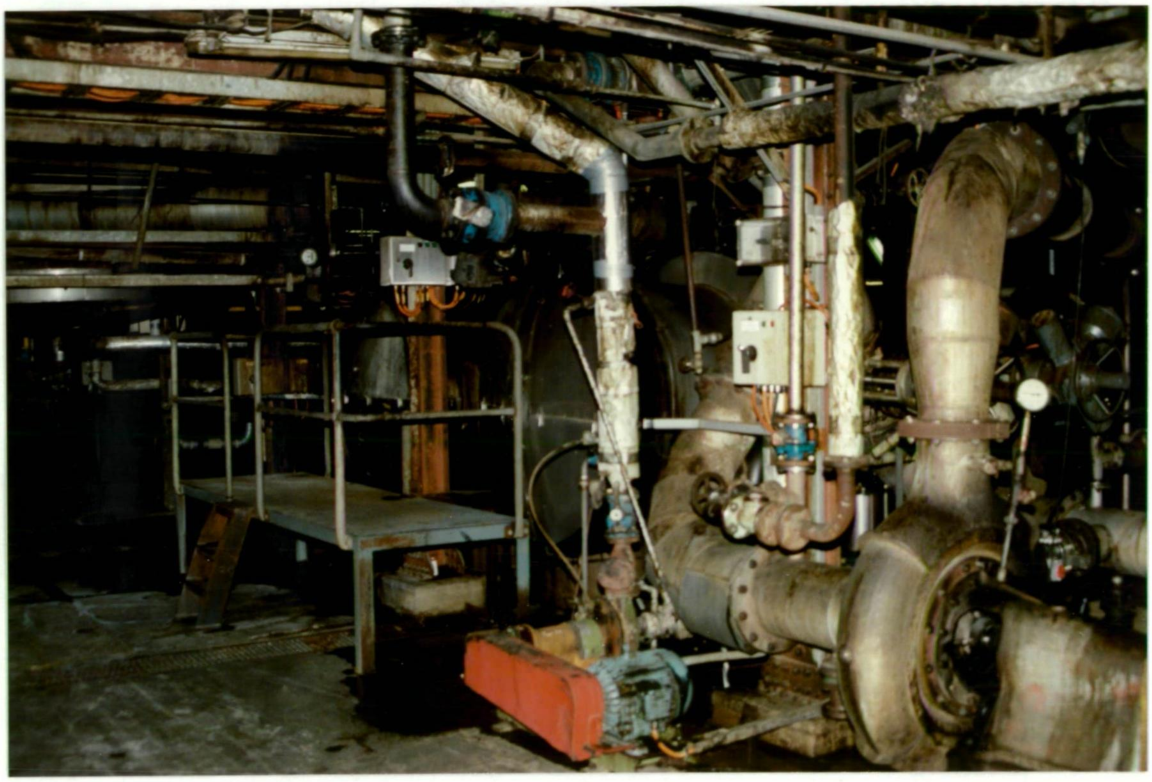

PLATE 3: Pump and calandria system. The circulation pumps are in the right foreground and the north calandria is in the centre. The south calandria is just visible behind it. The horizontal pipe leading from the pump then bending upwards leads to the finishing pan located on the next level.

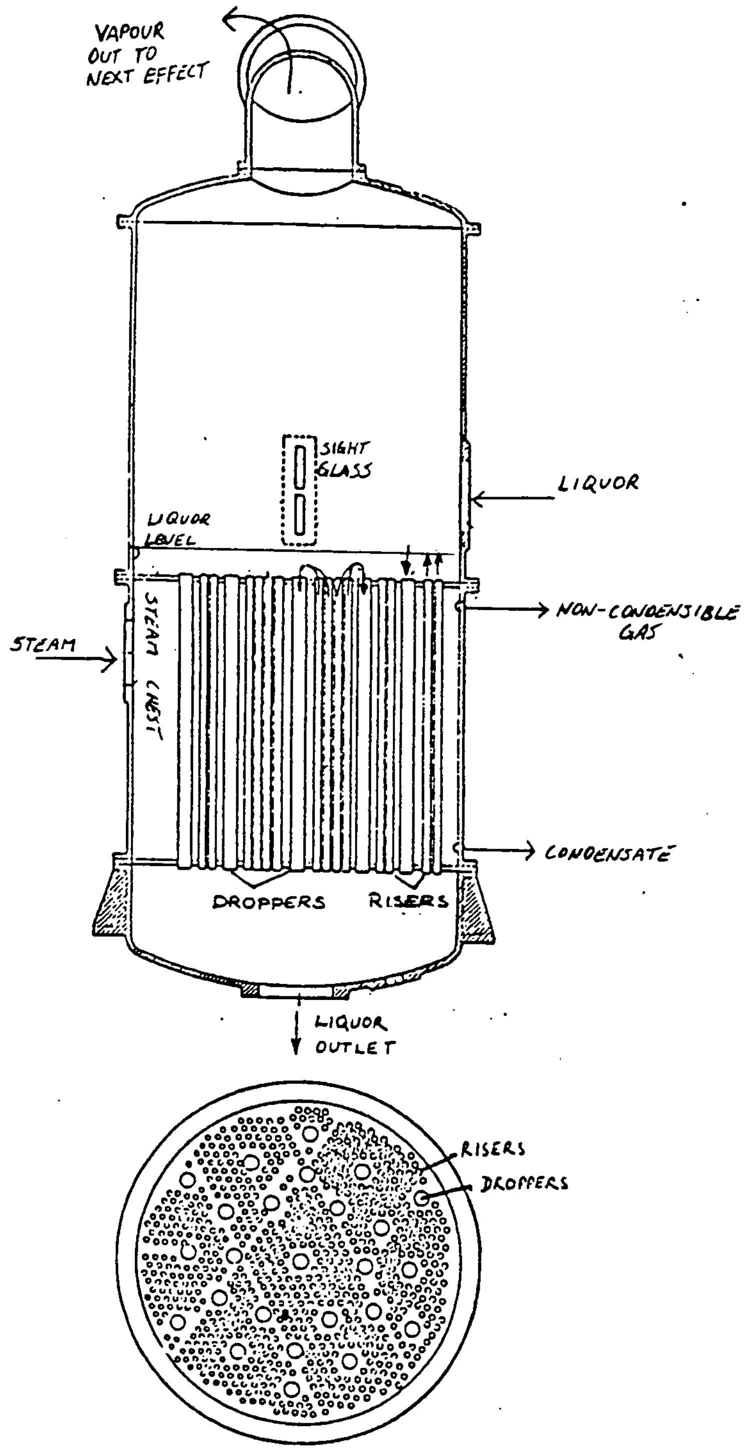

FIGURE 3: DETAILS OF AN EFFECT

EVAPORATOR TRAINING MANUAL (Associated Pulp and Paper Mills, 1986a)

Process steam is applied only to the first effect. As already stated the vapour produced is then used to heat the next effect. To do this the next effect must have boiling liquor at a lower temperature than the vapour to achieve heat transfer. For this to occur the effect must be operating at a lower temperature so the boiling point will be lower. This pressure gradient is achieved by a condenser steam ejector system on the fourth effect and the use of 210 kPa steam on the first effect.

Each set needs to be cleaned periodically to maintain efficient operation. The liquor side of the tubes get fouled with a build up of solidified black liquor. This is removed by boiling out the set with caustic soda. The steam side of the tubes get fouled with A.Q. (anthraquinone) scale which is removed by washing with dithionite.

ENTRAINMENT SEPARATORS (CYCLONES)

Vapour from the fourth effect passes into this device which removes liquor droplets from the vapour stream and returns them to the liquor extraction line from the fourth effect. Clean vapour passes on to the jet condenser in the case of No 1 set or the surface condenser in the case of No 2 set.

JET CONDENSER

The jet condenser consists of a chamber where the vapour is sprayed with cooling water. The condensing vapour causes the vacuum. The spray water and condensate is then pumped to No 2 evaporator pit and is then used to wash the raw pulp output (brown stock) from the digesters.

The amount of water entering the system is adjusted manually to give maximum vacuum. The water comes from the condenser pit, the ejector system condenser and fresh water.

Non-condensible gases from No 1 set are also vented into the jet condenser and are then withdrawn from the system by the steam ejectors.

SURFACE CONDENSER

This consists of a bank of heat exchanger tubes in a mild steel shell. Fresh water flows through the tubes and vapour condenses on the outside. Condensate is pumped to No 1 hot water tank. Cooling water goes to No 2 condenser pit or the No 1 hot water tank. The amount going to either is controlled automatically. Periodic maintenance is required to stop organic slime building up on the water side of the tubes (caustic boil out needed) or A.Q. scale building up on the steam side (dithionite wash needed).

EJECTOR SYSTEM

This is primarily to remove non-condensible gases from the system which if allowed to build up will cause pressure increases and vacuum problems. It operates by discharging a stream of high velocity steam across a suction chamber attached to the condenser vapour chest. Gas is entrained by the steam and carried into a diffuser.

CONDENSATE SYSTEM

Condensate is extracted from the base of each effect and cascades into the next. Condensate from No 4 effect is the total condensate from the system. As the condensate cascades from one effect to the next it flashes generating more steam which will heat the next effect.

Problems can occur when the liquor level in an effect becomes too high and there is carry over of liquor or froth into the next effect with the vapour. When this happens the condensate is contaminated and is useless for washing the brown stock (pulp output from the digester) and must be directed to the evaporator sump (drain).

Dumping condensate is costly both in terms of loss of thermal energy and caustic from the liquor. Problems here must be corrected as soon as possible.

FINISHING PAN - CALANDRIAS

This system consists of two calandrias and a flash vessel (see figure 4). One of the calandrias is always on wash cycle while the other is used for the finishing pan.

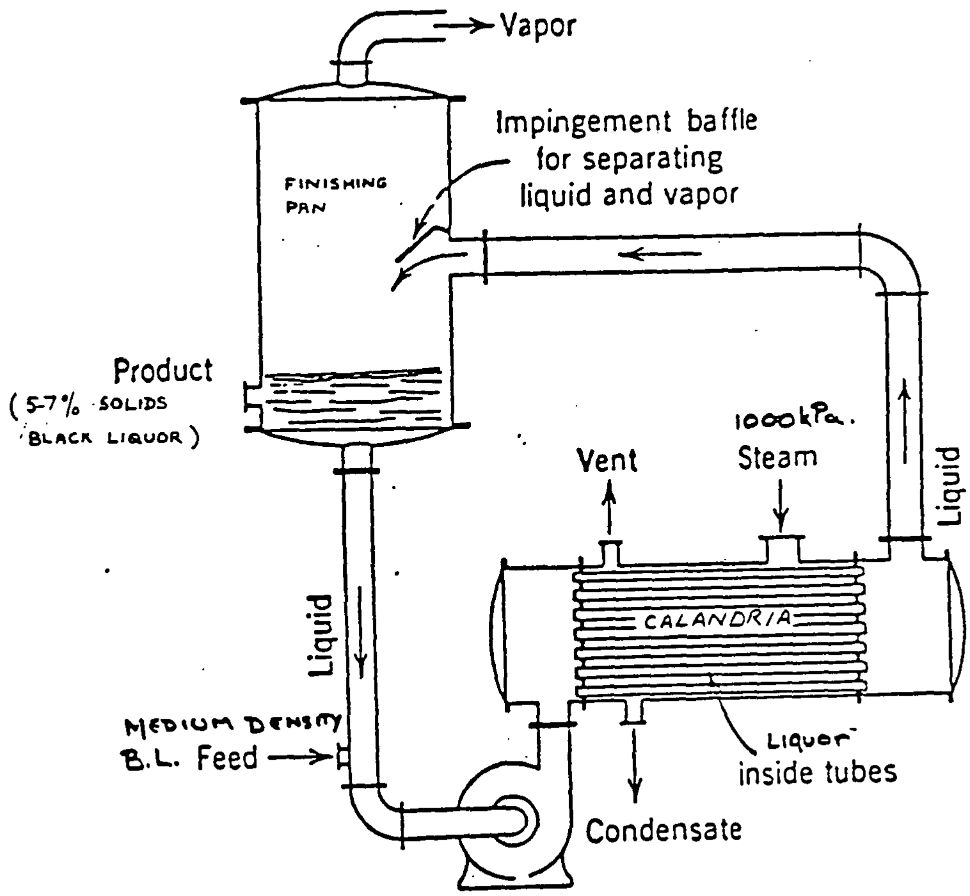

FIGURE 4: FINISHING PAN AND CALANDRIA

EVAPORATOR TRAINING MANUAL (Associated Pulp and Paper Mills, 1986a)

Liquor is pumped through the calandria (horizontal tube heater) at relatively high velocities. The tubes are surrounded by high pressure condensing steam. Liquor does not boil in the calandria because of the high circulation rates and pressure. The liquor then goes into the flash vessel (the finishing pan) where the vapour flashes off.

If liquor boils in the tubes solids will be deposited and heat transfer will be reduced which will affect performance. Deposits do build up which is why the calandria are regularly placed in wash mode.

Steam generated by this system is reused by sending it to the first effect of the multiple effect evaporators. Liquor droplets in this steam are removed by a cyclone and returned to the finishing pan vessel.

FALLING FILM EVAPORATORS

A diagram of a falling film evaporator vessel is shown in figure 5. There are three of these vessels, A, B and C. Two act as pre-evaporators and the third as a post-concentrator. C is always a pre-evaporator. B and A are alternated because when a vessel acts as a post-concentrator deposits build up. These deposits can be dissolved in the weak liquor in the vessel when it is operating as a pre-evaporator. Occasionally a caustic boil out is required if the deposits build up too much. The falling film evaporators have automatic Taylor controllers (plate 4) and alarm systems (figure 6).These are the most modern parts of the system and supplement the original multiple effect and finishing pan system.

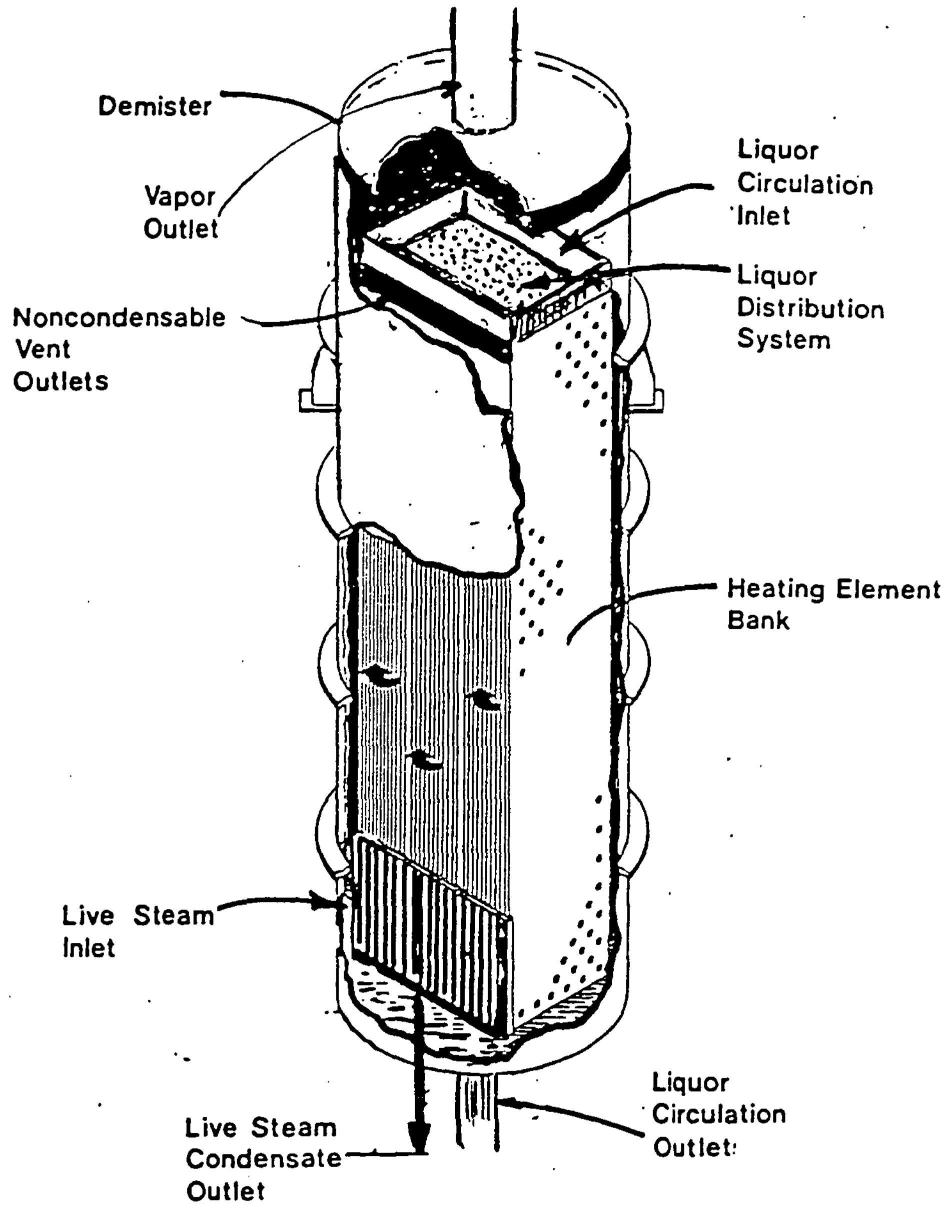

FIGURE 5: DETAILS OF A FALLING FILM EVAPORATOR

EVAPORATOR TRAINING MANUAL (Associated Pulp and Paper Mills, 1986a)

PLATE 4: Control Panel showing mimic diagram (top left) alarm panel (bottom left) and Taylor controllers (centre). This panel only controls the falling film evaporators.

INSTRUMENT AIR PRESSURE LOW	MEE DRIP TANKS CONDUCTIVITY HIGH C4199 C4200	MEE CONDENSERS CONDUCTIVITY HIGH C4332 C4333	FFE CONDENSATE CONDUCTIVITY HIGH C4416	CONDENSER COOLING WATER VALVE SHUT TV4411	. . .	PRIMARY BL TANK LEVEL HIGH L3558	78-302 NOT READY
INSTRUMENT POWER SUPPLY FAILURE	EVAPORATOR DRAIN SODA LOSS HIGH C3999-9	BL STORAGE DRAIN SODA LOSS HIGH C3999-10	CONTROLLER ALARM	FFE SURFACE CONDENSER LEVEL HIGH	BL BUFFER TANK LEVEL HIGH L3979	PRIMARY BL TANK LEVEL HI-HI L3558	PRIMARY BL TANK SUMP LEVEL HIGH
. . .	. . .	BOILING POINT RISE HIGH T4406	BL STORAGE TANK 1 LEVEL HIGH L3562	BL STORAGE TANK 2 LEVEL HIGH L3564	SPENT BL TANK LEVEL HIGH L3978	SBL STEAM RECOVERY CONDENSATE CONDUCT. HIGH C4959	HBL TANK 1 LEVEL HI-HI L3551
. . .	. . .	. . .	BL STORAGE TANK 1 LEVEL HI-HI L3561	BL STORAGE TANK 2 LEVEL HI-HI L3563	EVAPORATOR BL TANK LEVEL HIGH L4473/3980	SBL STEAM RECOVERY RAW WATER FLOW LOW F4957	SBL STEAM RECOVERY PRESSURE HIGH P4983

FIGURE 6: EVAPORATOR ALARMS: DETAIL OF ALARMS SHOWN IN PLATE 4

EVAPORATOR TRAINING MANUAL (Associated Pulp and Paper Mills 1986a)

OPERATION

HEATING SURFACE

The heating surface in each vessel consists of a bank of twenty heating elements made from two stainless steel plates. Condensing steam flows up into the elements and liquor flows down the outside (in a falling film) where it is boiled. Liquor is continuously circulated by a pump, product liquor being bled off from the pump discharge.

STEAM SYSTEM

Steam to vessels A and B is supplied through two thermocompressors. Thermocompressors are used to improve steam economy. The vapour boiled off in vessels A and B is used to supply a common header. Part of this is reused and the rest is used as the heating medium in vessel C.

Condensate flows from the bottom of the bank of elements into a condensate tank. Vessel A and B condensate tanks feed into the larger vessel C tank from where it is pumped into the process hot water tank No 1.

Condensate levels must be maintained below the heating elements to prevent water hammer which can damage them. This is prevented by non-condensible gas vents being positioned such that high condensate levels will seal them off causing a pressure increase and automatic steam reduction.

If the condensate is contaminated (liquor has got into the condensate) an automatic conductivity probe will open a dump valve to the drain as well as setting off an alarm. Once again the cause of contamination should be diagnosed quickly.

VACUUM AND NON-CONDENSIBLE GAS SYSTEM

Vessel C must operate under a vacuum. This is achieved by condensing the vapour boiled off vessel C in a surface condenser which operates in a similar way to the multiple effect set No 2 condenser. Non-condensible gases are removed using a steam ejector which also further supplements the vacuum.

3 METHODOLOGY

3.1 INITIAL ANALYSIS.

The reason for the choice of the Evaporator Section as the basis for this study has already been stated in section 2.2. However a more in-depth statement of the initial analysis needs to be made to show why this particular area was deemed suitable for the development of an expert system that could be used for multiple purposes, how the problem boundaries were defined and why the development tool used was chosen.

This study was the first serious attempt by APPM to introduce an expert system, therefore there was a need to make the project successful and demonstrate wider applications to management (Bonnet *et al.*, 1988). The system therefore had to be small enough to be developed by a small number of people but significant enough to impress management and users.

The boundaries of the problem were easy to establish as the evaporators have a single product input (weak black liquor) and a single output (heavy black liquor). The other inputs of consequence are production steam and cooling water. The only other output is condensate which is later used for washing wood pulp from the digestor.

After the problem area was isolated it was necessary to study the various sources of knowledge available. There was a large amount of documentation on the evaporators and access was given to several domain experts who were to help. The knowledge acquisition process is discussed in detail in the next section.

The initial analysis then followed the sequence identified by Harmon *et al.* (1988). First the type of event that initiates the problem solving sequence was identified. In the case of the evaporators this was either an alarm sounding or deterioration in performance of one of the evaporator components to the point where some maintenance had to be done (that "point" turned out to be difficult to identify). Secondly the end of the task had to be identified, which was the bringing of the evaporator back to optimum operation. This was determined in early briefings and tours of the plant.

The approach of Harmon *et al.* is then to identify in general terms how the problem was solved. In the case of the evaporator project it involved gathering data throughout the problem solving process rather than having all data on hand initially. This lent itself to a primarily backward chaining model.

Lastly a development tool had to be chosen before prototyping could begin. Due to financial constraints a rule based shell was decided on despite a frame based system having attractions in the systems training role.
VP Expert version 2.1 (Paperback Software International, 1989) was chosen due to its immediate availability, ease of use (Friederich and Gargano, 1989), low cost and favourable reviews (Harmon *et al.*, 1988, Pedersen, 1988).

3.2 KNOWLEDGE ACQUISITION

Knowledge for the system was acquired in three ways:

APPM documentation

Interviews with experts

Log sheets

3.2.1 EVAPORATOR DOCUMENTATION

The original prototype was based heavily on written material in the form of an Evaporator Training Manual (Associated Pulp and Paper Mills, 1986a) and a trouble shooting guide (Associated Pulp and Paper Mills, 1986b) an example page of which is in appendix B. Initially the diagnostic guide was used to develop rules and divide the evaporator section up into three logical areas: The multiple effect evaporators, finishing pan and falling film evaporators. Within these three several major subareas were identified around which the coarser or initial rules were developed. At first everything was in a single knowledge base. This was slow, unwieldy and difficult to maintain, even at the early stage. Waterman (1986) suggests that if a knowledge base reaches this stage it should be reassessed and redesigned. Therefore the rules were split into three knowledge bases which were equivalent to the three logical areas. Later a fourth knowledge base was added to deal with the alarms on the falling film evaporators.

Using the information from the trouble shooting guide a naive system was developed which could be used for diagnosis, but in a very limited way. Extra information was then added from the Evaporator Training Manual which was also the main operating guide. The knowledge obtained from the Evaporator

Training Manual was used mainly to add justification messages to the knowledge base. Operators could then ask why questions were being asked, and receive information about correct pressure, flow and vacuum levels. The detailed justification was also added to give explanations when the system was used in its training role.

By using the written documentation a very basic maintenance guide was also developed. However there were major shortcomings. In both documents cause and effect were sometimes difficult to resolve and terms like 'high' and 'low' predominated. What was needed was a statement of specific performance levels and what was regarded as unsatisfactory performance so maintenance could be scheduled. This was achieved by adding fuzzy rule sets after later interviews with experts.

3.2.2 INTERVIEWS WITH EXPERTS

Using the information gained from reading both the Evaporator Training Manual and diagnostic information and developing the initial prototype, a series of knowledge engineering interviews were arranged with the expert to sort out obvious deficiencies in the system. The initial interview was unstructured (Welbank, 1990), that is getting to know the expert and a general idea of how he solves problems.

After the first two interviews the primary expert left the company and Tasmania. Fortunately there were two other experts willing to help, one of whom had the added advantage of being in charge of evaporator training as well as providing expert trouble shooting advice.

An important development at this stage was the company's decision to review the training procedures, Evaporator Training Manual and the trouble shooting manual as a separate project in the evaporator section. This was probably the key to success of the entire expert system project as this redevelopment and the development of the expert system then started to run in parallel, with information elicited by the knowledge engineering interviews being included not only in the expert system but also in the new Evaporator Training Manual and associated documentation. These interviews tended to be prompted (Welbank, 1990) using specific cases or documentation as a basis for discussion.

The knowledge engineering exercise uncovered major problems with the original fault finding guide, the Evaporator Training Manual and even the technical drawings of the plant design which the expert used to explain certain procedures.

For example incorrect symptoms were being associated with particular incidents. Specifically flash over could be caused by low vacuum according to the fault finding guide. This was wrong, the correct information being that flash over could be a problem when vacuum was reestablished. The associated rule was deleted and warnings added to all output screens advising that a vacuum needs to be reestablished. An example of a problem in the Evaporator Training Manual was an incorrect description of part of the multiple effect evaporator system where a non-existent heat exchanger was shown. This problem came to light when questions were posed about its purpose. Another example of problems being detected was when the expert used a design drawing to illustrate a particular flow and discovered a pump in a closed circuit feeding itself. In the same interview using the same diagram two pumps appeared to be connected to each other by their output lines. The information gained at these interviews was therefore important to incorporate in the expert system and also to update the Evaporator Training Manual and other documentation.

As the knowledge engineering interviews continued my own expertise in the area of evaporators also increased. As a result more in-depth questioning about specific problems could be asked. Specific readings were obtained to predict when preventative maintenance should be carried out and confidence factors were included in a number of cases where there was either conflicting evidence or a variety of opinions as to what was a significant reading. As a result terms like 'high', 'low' and 'normal' were resolved. Interviews by this stage were of a structured nature (Welbank, 1990) concentrating on particular areas and problems.

A third expert was used to verify the information given by the other two experts. This person was a senior operator rather than an engineer and provided more operational information about the evaporators. Some of this information was gained directly from interview, the rest after he used the prototype expert system and discovered either problems or omissions. His knowledge allowed environmental information to be added to the system. For example heavy rain causes the western condenser pit to flood setting off the conductivity alarm. An example of an interview with this expert and the way a rule was developed and finally used in the system is in appendix C.

Towards the end of the knowledge engineering phase both experts were interviewed at the same time to resolve conflicting solutions to problems and further refine the fuzzy rule set. This involved adding confidence factors as a discussion revealed in all cases that both were giving the correct information but were giving differing weight to certain symptoms. Reaching a consensus was most difficult on the maintenance side where both experts used different criteria to decide when to do a caustic boil out or a dithionite wash (these are the main maintenance operations).

3.2.3 EVAPORATOR LOG SHEETS

An example of one of these forms is in appendix D. Initially a set of log sheets from a three month period was obtained and examined. Although not providing explicit details as to how problems were diagnosed (except in the case of a major failure), they did give an insight into the maintenance cycle. That is performance data could be traced to the point where maintenance was required. This point varied depending on the shift running the evaporators at the time, suggesting that a uniform method of determining when maintenance is due be introduced. A shut down usually means loss of production or overloading another evaporator element, however running an evaporator that needs maintenance is costly in terms of steam production and ultimately the unit takes longer to clean.

The log sheets also served as a useful basis to ask questions when interviewing the experts. It was by studying the log sheets that it was discovered that some parts of the evaporator readings were taken in pounds per square inch (PSI) and others in kilopascals (kPa). In the case of the Multiple Effects, number one set used PSI, number two set kPa, requiring extra rules and conversion equations to be added.

Information from the log sheets was later used to develop test data to verify the expert system's diagnostic and maintenance suggestions.

3.3 CONSTRUCTION OF THE KNOWLEDGE BASE

The knowledge base was built using *VP-Expert*, a cheap ($350) expert system shell. The final system consists of 265 rules contained in four knowledge bases.

Construction of the knowledge base was very dependent on the way the shell's inference engine arrives at a conclusion. This also affected the usefulness of the final system in relation to its use in multiple roles. To demonstrate this one needs to look at the construction of a VP-Expert program and the way its inference engine works.

A VP-Expert knowledge base consists of three main parts. First there is a procedural section referred to as the actions block. This is processed like a procedural program and allows initial facts to be set, messages to be displayed and loop controls to be implemented. It also specifies the objective of the consultation (the goal variable) with a FIND command. The evaporator expert system has a single goal variable which is the problem affecting the equipment.

The second part of the knowledge base consists of the rules block. The shell is primarily backward chaining although it can be, and in this system is, made to forward chain. Rules are tested depth first beginning with the first rule which contains the goal variable in its conclusion. If any of the conditions in the rule have variables which are unknown, further rules are fired or questions asked to determine whether that goal variable is true. As soon as one condition occurs which sets the rule to false, the next rule containing a goal variable is evaluated. Because of this the order of rules in the knowledge base is important so that most likely possibilities are checked first and unnecessary rules are not fired or unnecessary questions asked.

The other consideration in the ordering of the rules relates to the seriousness of a problem. Hence rules about significant failure problems (for example those which set off alarms) are checked before rules which predict maintenance and hence appear earlier in the knowledge base.

To ease maintenance of the knowledge base, rules are grouped by problem type. For example there are groups of rules which deal with pressure problems, others with vacuum problems. This grouping is not rigid however as not all diagnostic criteria fall into discrete areas. When groups of rules were set up, any rule that could be placed in several locations was placed with the group of rules which require its conclusions first.

Within these rule groups the first rules are the ones which suggest there is no problem and the last are rules for which the problem is unknown. For example in the Multiple Effect knowledge base after alarms are checked the next rule containing a goal variable is:

```
IF Problem_Area = Multiple_Effect AND
        Evaporation_Rate > 4 AND
        Set = No_1 AND
        Vacuum_Level > 22 AND
        Liquor_Carry_over = No_Alarm AND
        Dome_Pressure = OK AND
        Pan_Pressure = OK
THEN
        Problem_Solution = NONE
```

There is a similar rule immediately following for number 2 set. These rules immediately establish normal operation for the multiple effect evaporators. If the conditions in these rules are met a message confirming normal operation is displayed. There is a similar structure in the Falling Film and Finishing Pan knowledge bases. Situations where there is a problem but no known solution often require more investigation and hence have the longest rules or largest number of rules to fire. To avoid unnecessary questions these are placed last in a group.

Also important is the order of the variables being checked in the condition part of the rule. Those variables which are most discriminating and easily measured are placed first in a rule. Hence variables of pressure and vacuum need values early in the consultation so rules containing deep knowledge about the plant's operation are fired early in the consultation and unnecessary search paths are then eliminated. For example the following rule from the multiple effect evaporator knowledge base sets several variables to no, representing situations which cannot occur in the case of poor heat transfer.

```
IF Problem_area = Multiple_Effect AND
        M_E_Problem = Low_Vacuum AND
        Poor_Heat_Transfer = YES
THEN
        DISPLAY "Investigating cause of poor heat transfer"
        Probable_Cause = P_H_T
        Ejector_Problem = NO
        Air_Leaks = NO
```

It is also important to order the variables in a way that reflects the expert's reasoning so there is a logical path to queries when the system is being used in a training mode. This will result in the order of user questions being the same as the experts' search for facts.

The final part of the system involves statements which are used to generate questions to the user and, where necessary, give a menu of possible responses.

These are displayed when the inference engine finds a variable for which there is no value in the knowledge base. Unless a reading is required the range of user responses is displayed as a menu. This was done for ease of use, and also, within the training role to make a trainee aware of the various symptoms they could meet.

Explanations are attached to the rule requiring a value for a variable, not to questions, and are activated by a user selecting the WHY option. Hence a question can be activated by different rules in different consultations causing different explanation to be shown because the context and significance of the question may have changed. From a training point of view this is important.

Conclusion messages are attached to the rules containing goal variables because of the large number of different messages that need to be displayed. Hence the goal variable's final value is important only to the extent the appropriate message is shown. The value of the goal variable is never displayed to the user. These concluding messages were a primary consideration when building the knowledge bases and reflected its multiple uses. As a result there are three types of final messages. The first type is displayed when a problem is found. In these cases a recommended course of corrective action is given. A message of this type would be expected in either a diagnostic, training or a maintenance consultation.

The second type of message is displayed when there is a problem but no solution can be found. These messages are normally only seen during a training consultation where various possible scenarios were being tried.

The third type of message is displayed when no problem can be found. That is if the evaporators are operating within their performance parameters. This type of message would generally be seen when the system is being used for maintenance.

Several problems encountered in using the selected shell do, however, need to be mentioned.

The major problem encountered in building the system was with part of the explanation facility. The 'WHY' option presented no problems. This displays the text in the 'BECAUSE' part of a rule and is activated when a user wishes to see why a particular question is being asked. As already stated a lot of time was spent on this aspect because of the system's training role.

The 'HOW' explanation facility which is supposed to state how a conclusion was reached is not very good and is confusing for novice users. To overcome this problem the system was designed to display justification messages as it chained through the knowledge base and reached intermediate conclusions during a consultation. The challenge was to make these messages as concise as possible to avoid unnecessary blocks of text appearing during a consultation but at the same time justifying why a particular action was being taken. User feedback suggests this aim has been achieved.

A second problem with the shell is its slowness in loading a large knowledge base. This is because it has to interpret the rules every time they are loaded. This speed of loading could be improved up by running the expert system on hardware with a faster processor or purchasing a run-time version of the shell. Surprisingly this speed problem was not mentioned by the operators.

3.4 TESTING

Testing was carried out throughout the development of the system (Harmon *et al.* 1988). Initially this was to ensure the system gave correct results and degraded gracefully at the edge of its knowledge domain. The following message is an example of what is displayed in such a situation :
"The cause of high pressure in No 1 pan steam chest in the M.E.E. sets is poor heat transfer. However a more specific diagnosis cannot be made given this systems knowledge of the M.E.E. sets. Please note the problem and its solution so this system can be updated".

At certain stages when part of the system was near completion an extensive set of tests were made to check the various paths and solutions in the system. This was done by an evaporator operator and one of the domain experts who independently systematically worked their way through the system noting solutions and problems as they went. Problems were investigated with the domain experts and fixed. In this way the diagnostic and maintenance aspects were checked.

The final stage of testing was to let evaporator operators use the system and suggest changes before it became fully operational as an aid to fault finding and diagnosis. This was done by giving a senior operator a list of four month's worth of incidents elicited from the log sheets and getting him to run through them comparing his problem solving sequence and conclusions with that of the expert system. This test data consists of a mixture of maintenance and fault problems. The system performed quite well but once again some problems arose which were corrected. A summary of the test data used in these tests is given in appendix E.

The systems in its training role was tested by the Pulp Mill Training Co-ordinator who used a selection of the data. The intermediate justification messages and the 'WHY' facility messages were reviewed and in some cases modified.

Finally the system was given to shift operators to use as an assistant on the job, initially in an informal manner. Appendix F contains an evaluation of the system and recommendations for action by APPM. It should be noted that this was done on 5th December 1990. The system has since been updated and solves all test problems.

4 RESULTS

The development of an expert system which could be used for multiple purposes has to be evaluated in terms of how well it meets the requirements of fault diagnosis, training and maintenance.

4.1 DIAGNOSIS COMPONENT

Test data was derived from the evaporator log sheets. All incidents between 17 April 1990 and 23 August 1990 were tabulated and applied to the system. There were a total of 90 incidents of which 42 were of a maintenance nature and the remaining 48 of a general nature. The date, unit, problem and critical pressure readings are recorded in appendix E. Those incidents which fell into the general category were used to test the fault diagnosis system. At the start of the testing period the system gave correct responses in all but two cases. In those cases the system was examining the correct fault area but responded with a message that it could not find the fault given its current knowledge of the system. Extra rules were then added to overcome this problem. By the end of the testing period the system was giving a correct diagnosis in all cases.

Although these test cases were a realistic test of the system, there were many incidents allowed for in the system which did not occur in the test period. A senior operator therefore began to test the system by exercising all possible paths through it, verifying results and messages. This was a time consuming process and lead to the discovery of several "dead ends" where no solution or ending message was given. These problems together with a series of minor errors were corrected.

For final verification the test data was given to two other senior operators who then repeated the process described above. The system performed with no adverse reaction from the operators.

It is impossible to state that the system is 100% correct as new rules are being added continually. This is due to new problems arising as the equipment ages and also as a result of modifications to the equipment, for example the addition of new valves and sensors. Therefore the expert system, although out of the prototype stage, is still under active development.

The system is operational for diagnosis but not in the control room of the evaporator section. Currently it is running on a computer in the Pulp Mill Training Centre but the recommendation in paragraph 3 of appendix F to locate a microcomputer in the control room has been approved.

4.2 TRAINING COMPONENT

In its role as a training system the expert system has been used in conjunction with other training materials which included a video disk and microcomputer based learning package as well as notes and manuals. This material has been compiled by APPM and packaged by Box Hill TAFE. The video disk and microcomputer part of the learning package was a Canadian production which gave basic but not specific information on evaporators. Since all chemical pulp mills use different configurations of evaporators (including valves and pipes) the expert system has been used to give training specific to the Burnie plant by acting as an intelligent tutor. The course is split into two parts, a knowledge module and a skill module. In both of these the trainee operator is required to do self help questions. If they have difficulties finding a solution they use the expert system to step them through the problem.

A data base of problems (which have been run through the system) has been established and a selection of these is given to the trainee at the end of training. They are asked to provide solutions which are then checked against the system solution.

Quantitative evaluation of the system's effectiveness in training was not possible as insufficient trainees had used the system. Also insufficient time had passed since completion of the system to evaluate any improvement in skill levels of operators who had trained using the system over those who had not.

4.3 MAINTENANCE COMPONENT

Approximately half of the incidents reported in the evaporator log sheets could be regarded as maintenance problems (42 incidents). Of these the majority were caustic boil outs (39, of which ten were for the falling film evaporators, the remainder the multiple effects) and the rest dithionite washes (multiple effects only). These were further investigated by tracing back through the log sheets to determine where the expert system would have suggested maintenance was required. The system suggested maintenance was required on average four days before it was actually carried out in 26 cases and agreed with the operators in the remaining cases. The worst case in the test period was when the system suggested a caustic boil out on the 6th May, but one was not done until the 21st May by which time evaporation rates were extremely low. In another case on 3rd September 1990 (not in the formal test period but using a real-time incident) the system suggest a dithionite wash while the operators performed a caustic boil out. The system turned out to be correct.

Despite its performance as a predictor of maintenance and managements enthusiasm for its use, this usage of the system was the only segment not to be implemented except as an extension of the diagnosis component. Management's reason for not wanting to implement this usage of the system was they wanted the recommendations in appendix F on standardisation of instrumentation in the evaporator section to be implemented first. This is expected to take about 12 months. When these instruments are installed they want the system to not only predict problems but also to log readings. This is technically feasible as *VP-Expert* will interface with a database.

5 DISCUSSION OF RESULTS

The results of this project have been presented in terms of how well the expert system performed in its three roles. What now needs to be evaluated is the system's advantages and performance in its integrated role of diagnoser, training package and maintenance predictor. Certain aspects of the development methodology also need to be discussed, particularly the use of multiple experts and the practicality of developing a medium size system on microcomputer-based cheap shell.

5.1 MULTIPLE USE SYSTEMS

Most expert systems are developed with a single use in mind. They are used for diagnosis, process control, process engineering and training. Generally the only multiple use involved is in the secondary role of training. Development of a system for multiple roles however has advantages where those uses overlap. In the evaporator expert system the interface (as well as the knowledge base) being used in the training package is identical to the one trainee operators will be using when they are on the job. The system therefore not only trains them in the operation of the evaporators in a non-threatening environment but also teaches them how to use the system itself.

To do this no attempt was made to model the trainee's cognitive behaviour such as the keyboard tutor of Amato and Tsang (1989) . Rather the approach taken by Gregor *et al.* (1989) was adopted. This assumes that all trainees are at a similar level when they start the course. Because of this a greater emphasis had to be given to the explanation facility to provide in-depth tutoring.

The diagnosis and maintenance prediction components are complementary to each other and therefore were easier to integrate than the training component. The maintenance prediction part is designed to be used at a fixed interval (once every two hours, the same as current manual logging) so an optimal maintenance cycle can be implemented. However if some other part of the evaporator system starts to give problems this will be picked up as part of the standard consultation. The system's rules cannot distinguish between maintenance and general problems rather key indicators on the evaporator instrumentation are checked.

The development of an expert system with multiple uses also has advantages in terms of maintenance. As equipment is modified or new problems occur a single knowledge base has to be updated rather than multiple knowledge bases covering the same domain area but being used for different purposes. The evaporators are constantly being modified both mechanically and electronically, so this is a major consideration in the usage of the system.

5.2 DEVELOPMENT METHODOLOGY

The system was developed using a traditional prototyping methodology but with the use of multiple experts. Considerable debate has raged over the use of single or multiple domain experts in the development of expert systems (Rantane, 1990, O'Neill and Morris, 1989). This system was initially developed using a single expert, but after he left APPM, it was completed using two and at one stage three experts. More knowledge was elicited and elicited more easily while working with multiple experts than with the single expert. A reason for this may have been that the original expert was planning to leave anyway and may not have been motivated to do any major work before he left. The three who replaced him on the other hand were motivated as they were also responsible for a major review of the evaporator operator training course and the evaporator documentation including manuals and blueprints. As a result the knowledge engineering and the redevelopment project complimented each other. Personality also played a part. After the primary expert left the three remaining experts did not have an identifiable leader who could be regarded as the primary expert. Rather they worked together to solve problems and each had an area where they had more expertise than the others. For example one of the experts was also in charge of training. His knowledge of how to explain things to trainees as well as his experience as a process engineer helped considerably in the development of the training component. A second expert had responsibility for the electronic and monitoring devices, the third was an experienced supervisor with in depth knowledge of day-to-day mechanical problems.

Although disagreements did occur during interviews when more than one expert was present, the discussion served as a communication tool and a consensus was arrived at. There were no serious arguments encountered and, as stated in the results, the final system was accepted by three other senior operators who had not been involved in the development exercise.

5.3 CHEAP MICROCOMPUTER BASED SYSTEMS

The evaporator expert system was successfully developed with a cheap shell using a microcomputer. This is unusual compared with cases quoted in the literature, especially from the mid 1980's (Beaverstock, 1985). The result was more in line with Lukas and Keyes (1989) prediction that more systems would be developed on general purpose microcomputers using cheap shells. Examples of this prediction coming true can be seen in other industrial settings (Freeman *et. al.*, 1990). However although this was developed on a microcomputer it was relatively small (40 rules) compared to the evaporator expert system.

A cheap development platform has advantages to management as a low capital outlay is required. The risk is relatively small and it has the advantage of proving the technology. The main disadvantage that was discovered was the system tended to be slow loading the knowledge base.

6 CONCLUSIONS

The development of an expert system for multiple uses is both practical and desirable. In the case of the evaporator expert system the fields of diagnosis, maintenance and training were covered. The advantages of this approach is that trainees get to train on a system they will use on the job, overlap between maintenance and diagnosis are covered by common rules and a single knowledge base needs to be maintained.

Such a system can be developed on a microcomputer using a cheap commercially available shell. This reduces the risk to the company whose main financial cost becomes that of the personnel involved. If major cost savings can be shown, as was the case with the evaporator expert system and the hands-on users are enthusiastic about its use, it stands a good chance of success.

Multiple domain experts in the development of such a system can be highly desirable, especially if there is no one person who is regarded as the ultimate authority. Beginning with one expert to get an overview of the domain then moving to interviews with the other experts gave a good coverage of the subject domain and resulted in a system which all of them were happy with.

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APPENDIX A

CAREER PATH FOR OPERATORS

The following page shows the career path by job function of operators at the APPM Burnie Pulp Mill. There are three career streams an operator can elect to enter when level three is reached. The fibre stream and the recovery stream both require personnel to have been evaporator operators before they can advance beyond level four to more senior positions and hence a higher wage (indicated at the top right of each level box).

APPM BURNIE PULP MILL - CAREER PATH BY JOB FUNCTION

APPM

L6	SEPA B/P OPN.	ADV. DIGESTER B/P OPN.	DARS SENIOR OPERATOR	115%
L5	EPA B/P TESTING	DIGESTER B/P TESTING	WAO SENIOR OPERATOR DARS 1	110%
L4	CAPA S/C OPERATION	EVAPORATORS S/C BLEACHING	EVAPORATORS WAO	105%
L3	LIME KILN MOL MAKING WASH & SCREEN	WASHING S/C REFINING RE-CAUST.	SENIOR RE-CAUST. LIME KILN ROT. OP.	100%
	BLEACHING AND BLEACH CHEMICALS STREAM	FIBRE STREAM	RECOVERY STREAM	

L2 — 95%

WOODROOM ATT. | POTMAN | EVAP. ASST. | WOODROOM OP. | RINCA 2

SEMI ASST. | CHIP SCREEN ATT. | DARS 2 | CLEANER

L1 — 90%

ASSISTS IN JOBS AS PART OF A TEAM OR WORKS UNDER DIRECT SUPERVISION

L0 — ON COMMENCEMENT — 85%

ASSISTS IN JOBS AS PART OF A TEAM OR WORKS UNDER DIRECT SUPERVISION

APPENDIX B

SAMPLE PAGE FROM THE FAULT FINDING GUIDE

PROBLEM	CAUSE	ACTION CHECK LIST

MME SETS - NO. 2 SET

5. Liquor carry over with vapour	Excessive foaming	CHECK alkalinity, liquor temperatures, air leaks
	Liquor levels in Effects too high	Bring levels back into control by adjusting manual valves.
	Loss of extraction from first or fourth Effects.	CHECK extraction pumps
	Loss of vacuum	CHECK condenser and steam ejector operation.
	Tube(s) leaking in the Calandria of Effects	CHECK overhead operating pressure for deviation from normal.

APPENDIX C

RULE DEVELOPMENT FROM AN INTERVIEW TRANSCRIPT

The following is an edited interview dialog between one of the experts, in this case Richard Ambrose (R) and myself acting as knowledge engineer (KE).

R: There is a problem in the system here, with the flashover information.

KE: I took that from the fault finding sheets.

R: Yes well that's OK and most of it is right but there are a few things missing. We have alarms to detect flashover.

KE: I thought only the falling films had alarms.

R: No, we have alarms on the multiple effects as well.

KE: There is nothing about them in the manuals.

R: They are quite new. There is the condensate conductivity alarm and the drip tank conductivity alarm.

KE: Does this detect flashover on both sets?

R: Yes, there is one of each alarm on each set.

KE: What could set off the drip tank conductivity alarm?

R: Generally the liquor level in the effects being too high, excessive foaming or the finisher flashing.

KE: I thought the finisher was a separate system.

R: Yes, it is, but its one of the main reasons for the alarms and you haven't mentioned it in your system.

KE: Why does the finisher flashing set it off?

R: Vapour from the finisher is used along with process steam to heat the first effect of both sets. If liquor carries over with that vapour the alarms on both sets go off.

KE: So if both drip tank conductivity alarms are sounding it means there is flashover from the finisher?

R: Yes because with the other two reasons the alarm goes off on only one set.

KE: What is the usual cause of the finisher flashing?

R: Really the only cause is the post concentrator extraction pump being stopped which causes the liquor level in the finisher to rise to the point where it starts to flash.

The consultation then continued with information about the other alarms including the fact that rain can set off the drip tank conductivity alarm.

The above consultation was translated into the following knowledge base rule:

```
RULE LIQ_C_O1BA
   IF M_E_PROB_AREA = D_T_C AND
     BOTH_ALARMS = YES
   THEN
     DISPLAY "The drip tank conductivity alarm is being caused by the
finishing pan flashing over. This in turn is
probably caused by the post concentrator extraction
pump being stopped causing the finisher level to rise.
Since vapour from the finisher goes to heat the first
effect the alarms both go off.~"
PROB_SOLUTION = FINISHER
BECAUSE "Both alarms sounding would suggest contaminated vapour from the
finisher flashing";
```

APPENDIX D

LOG SHEET

EVAPORATORS LOG SHEET

TIME	PRE-EVAPORATOR						No. 1 MULTIPLE EFFECTS							No. 2 MULTIPLE EFFECTS							FINISHER				POST CONCENTRATOR						
	FLOW VESSEL A	FLOW VESSEL B	FLOW VESSEL C	CONCENTRATION IN	CONCENTRATION OUT	EVAPORATION	NO. 1 CAL. PRESS	NO. 1 PAN PRESS	NO. 4 PAN VAC.	FLOW IN	CONCENTRATION IN	CONCENTRATION OUT	EVAPORATION	NO. 1 CAL. PRESS	NO. 1 PAN PRESS	NO. 4 PAN VAC.	FLOW IN	CONCENTRATION IN	CONCENTRATION OUT	EVAPORATION	FLOW IN	CONCENTRATION IN	CONCENTRATION OUT	EVAPORATION	FLOW OUT	CONCENTRATION OUT	EVAPORATION	TOTAL EVAPORATION	HEAVY BLACK LIQUOR STORAGE	CALANDRIA	W.A.O. SCREEN
0800	13.0		12.5	36	38	1.35	29	5	20	10.4	37	53	3.13	28	2	21	8.4	37	49	2.05	8.5	51	57½	0.96	6.3	57½	TO EST	7.49	130	N	SS
1000	13.0		12.5	34	35	0.72	28	3	20	10.4	35	48½	2.89	21	1	24	9.2	35	47	2.34	8.5	51	65½	1.88	5.4	72	0.48	8.31	120	N	✓
1200	13.0		12.5	27	29	1.75	27	3	20	10.4	28	48½	4.39	20	1	24	9.2	28	42	3.06	8.5	46½	61½	2.07	5.5	66	0.37	11.64	98	✓	✓
1400		13.0	12.5	27	29	1.75	27	3	20	10.2	28	49	4.37	14	0	24	9.0	28	43	3.13	8.5	46	61½	2.14	4.8	66	0.32	11.71	105	S	✓
1600		13.0	12.5	25	26	.98	28	+2	21	9.8	24	44	4.45	13	+2	22	9.6	24	36	320	8.5	39	54	236	4.9	61	.56	1155	31	S	S2
1800		13.0	12.5	25	27	1.88	27	+1	21	10.0	25	50	500	12	+2	22	9.0	25	36	275	7.5	41	57	210	4.0	63	.38	1211	7	S	✓
2000	13.0	–	12.5	28	31	246	28	+2	21	10.0	27	47	425	14	+3	23	8.6	27	43	320	8.5	45	61	223	4.9	63	.15	1229	20	N	✓
2200	13.0		12.5	27	32	329	28	+1	21	10.0	27	46	413	13	+2	22	8.7	27	40	282	8.5	44	59	216	4.8	62	.23	1263	0	N	✓
2400	13.0		12.5	29	32	2.39	29	+2	20	10.0	29	42	3.09	13	+2	22	8.8	29	40	242	8.5	44	56	2.12	5.2	63	0.57	10.59	12	N	S2
0200		13.0	12.5	28	31	2.46	28	+2	20	10.0	28	51	4.50	18	+4	22	8.7	28	46	3.40	8.5	47	62	2.05	4.9	65	0.22	12.63	41	S	✓
0400		13.0	12.5	27	30	2.55	28	+2	20	10.0	26	47	4.46	17	+4	22	8.6	26	42	3.27	8.5	45	61	2.22	4.9	67	0.43	12.93	80	S	✓
0600		13.0	12.5	26	28	1.82	28	+3	20	10.0	26	44	4.09	17	+4	22	8.6	26	41	3.14	8.5	44	57	1.93	5.4	63	0.51	11.49	107	S	✓

7 A.M. INTEGRATOR READINGS

NO. 1 SET M.E.	STEAM	039762
	BLACK LIQUOR	5092385
NO. 2 SET M.E.	STEAM	238676
	BLACK LIQUOR	0796445
FINISHER CAL.	STEAM	9864636
	BLACK LIQUOR	6134117
FALLING FILM	STEAM	2113533
H.B.L. FLOW		5470074

BY. PASSING. HBL. TO EST AT. REDUCED TABLE. FROM. 7.00 TO 11.00. AM. ALK 15.8 @. 10.15 AM.

TIME	No. 1 SET												No. 2 SET													
	PRESSURE & VACUUM						TEMPERATURE °C						PRESSURE & VACUUM							TEMPERATURE °C						
	NO. 1 CALANDRIA	+ PRESS—VAC NO. 1 PAN	NO. 2 PAN	NO. 3 PAN	NO. 4 PAN	HEATER	TO NO. 2 PAN	NO. 1 PAN	NO. 2 PAN	NO. 3 PAN	NO. 4 PAN	HEATER	NO. 1 CALANDRIA	+ PRESS—VAC NO. 1 PAN	NO. 2 PAN	NO. 3 PAN	NO. 4 PAN	HEATER	CONDENSER	TO NO. 2 PAN	NO. 1 PAN	NO. 2 PAN	NO. 3 PAN	NO. 4 PAN	HEATER	CONDENSER
1000	28	3	4	13.	20			112.	96	88	68		21	1	6	15.	24		83	93.	112	102.	83.	66		128.
1400	27	3	5	16	20			112	100	88	65.		14	0	7.	16	24.		84	92	111	99	82	64.		125
1800	27	+1	-6	15	21			108	93	85	66		12	+2	-2	11	22		79	94	113	103	89	66		130
2200	28	+1	-5	15	21			109	94	86	68		13	+2	-3	12	22		79	94	112	103	87	67		130
0200	28	+2	-4	15	20			110	95	85	68		18	+4	0	10	22		77	95	116	105	90	68		139
0600	28	+3	-3	13	20			110	96	88	70		17	+4	0	7	22		77	94	116	105	94	68		139

COMMENTS

D/S B.L.F. CLEANED 12.5.—12.25.
CHANGE. TO SOUTH. CAL& VESSEL A @ 1-20.
DARS TAKING. LIQ. AT. VARIES INTERVALS.
FROM. 11.00. AM.

A/S CHANGED TO NTH. CAL. & "B" VESSEL 1810.

N/S Changed to Sth Cal + Vess 'A' at 1.30
Cleaned Black Liquor Filter

D.E. 8.00 A.M. 12 / 6 / 89

PM F 1950 — NWPS 50059

APPENDIX E

TEST CASE SUMMARY

The test cases on the following pages represent a four month sample of incidents with the evaporators compiled by APPM. It shows the date of the incident, the unit affected, a brief statement of the problem and the critical readings observed. They are a summary of the test data which was taken from the log sheets. In all cases other information is entered by an operator to arrive at a conclusion. This is in the form of other readings or observations about the equipment. A full sample consultation using the expert system is in Appendix G.

PROBLEMS ASSOCIATED WITH THE EVAPORATOR SECTION

17th April,1990 to 23rd August, 1990

DATE	UNIT	PROBLEM/ACTION	
17.4	No.1 M.E.Evap.	No.4 Pan Level High Caustic boil out.	 o/head press.+9 s/chest 20psi
	No.2 M.E.Evap.	Caustic boil out.	o/head press+10 s/chest 23psi
18.4	No.1 M.E.Evap.	No.4 & No.1 Pan level high	
21.4	No.2 M.E.Evap.	Caustic boil out	o/head press+10 s/chest 20psi
25.4	No.2 M.E.Evap.	Surface Condensor vac low -65 kpa.	
26.4	F.F.E.'s	Pre-evaporators flashing over incoming density 20.	
27.4	No.1 M.E.Evap.	Caustic boil out Low vacuum	o/head press+2 s/chest 30psi
6.5	No.2 M.E.Evap.	Low Vacuum	-59
12.5	"	Low Vacuum	-55
19.5	"	Low Vacuum Evap.Rate 2.9 l/sec.	-53
21.5	No.2 M.E.Evap.	Caustic boil out	o/head press+10 s/chest 24psi
22.5	No.1 M.E.Evap. F/Pan	Dithionite washed Level high	 Post Conc. S/Pump us.
23.5	No.2 M.E.Evap. No.1 M.E.Evap.	Dithionite washed Caustic boil out	 o/head press+9 s/chest 15psi
24.5	F.F.Evaps.	Caustic boil out	

3.6	No.1 M.E.Evap.	Caustic boil out	o/head press+10 s/chest 20psi
	No.2 M.E.Evap.	Caustic boil out	o/head press+9 s/chest 20psi
5.6	No.1 M.E.Evap.	No.4 Pan Level High	
	No.2 M.E.Evap.	Caustic boil out	
	F.F.E.'s	Require caustic boil out	
6.6	No.1 M.E.Evap.	Requires caustic boil out e/r 2.8	
	No.2 M.E.Evap.	Requires caustic boil out.	
8.6	No.1 M.E.Evap.	Caustic boiled out.	
10.6	F.F.E.'s	Flashing over incoming tw.24 E/R 3.3	
12.6	M.E.E.s	Supply Pump replaced	
14.6	No.1 M.E.Evap.	Caustic boil out	
15.6	F.F.E.'s	Require caustic boil out E/R 2.9	
16.6	F.F.E.'s	Caustic boiled out E/R now 5.2.	
18.6	No.1 M.E.Evap.	Low vacuum (-14 No.4 pan).	
19.6	No.1 M.E.Evap.	Caustic boiled out.	
22.6	No.1 M.E.Evap.	Requires caustic boil out	o/head press+9 s/chest 17psi
26.6	No.1 M.E.Evap.	Caustic boil out	o/head press+7 s/chest 12psi
	No2 M.E.Evap.	Requires caustic boil out	o/head press+10 chest 20psi
27.6	No.1 M.E.Evap.	Drip Tank Ext.Pump replaced	
28.6	F.F.E.'s	Requires caustic b/out E/Rate 2.6	
	No.1 M.E.Evap.	E/Rate 1.85	o/head press+3 chest 4 psi

1.7	No.1 M.E.Evap.	Caustic boil out.
	No.2 M.E.Evap.	Caustic boil out.
3.7	F.F.E.'s	boiled out
4.7	No.2 M.E.Evap.	Requires caustic b/out o/head p.+10 s/chest 19
5.7	No1 M.E.Evap.	Requires caustic b/out o/head p.+8 s/chest 14 e/rate 2.4
9.7	No1 M.E.Evap.	Requires caustic b/out o/head p.+9 s/chest 16 e/rate 2.8
10.7	No.1 M.E.Evap.	Caustic b/out
11.7	No.1 M.E.Evap.	Dithionite washed
12.7	No.2 M.E.Evap.	Caustic boil out
13.7	F.F.E.'s	Low E/Rate 3.41
14.7	No.1 M.E.Evap.	Caustic boil out o/head p+9 e/rate still low s/chest 20
15.7	No.2 M.E.Evap.	E/Rate 1.85 o/head p+9 *(No.4 Pan Tube) s/chest 20
16.7	No.2 M.E.Evap.	Shut Mech repairs. o/head p+9 Not Caustic B/Out s/chest 19 E/Rate 2.9
	F.F.Evaps.	Post Conc.LCV blocked Post Conc.Level High
18.7	F.F.E.'s	E/Rate 1.81 Flash overs occuring. Incoming Tw 26/18 Req, Caustic B/out.
19.7	No.2 M.E.Evap.	Caustic b/out & dithionite washed Pre evaps caustic b/out !!!
21.7	No.1 M.E.Evap.	Req. Caustic b/out o/head p+8 s/chest 13 e/rate 2.9
24.7	No.1 M.E.Evap.	Req. Caustic b/out o/head p+10 s/chest 16 e/rate 3.2

25.7	F.F.Evaps.	Changed vessels 4x ? - f/overs?	
26.7	No.1 M.E.Evap.	Req. Caustic b/out	o/head p+10 s/chest 18 e/rate 1.4
	No.1 M.E.Evap.	Req. Caustic b/out	o/head p+12 s/chest 23 e/rate 1.6
	F.F.Evaps.	Caustic B/out	
27.7	No.2 M.E.Evap.	Caustic b/out	
	No.1 M.E.Evap.	Caustic b/out	
28.7	All Units good run E/R's 18-19 l/Sec.		
2.8	No.'s 1 & 2 Set F.F.Evaps.	Caustic b/out Shut	
4.8	Liquor returned from DARS & circ. back - incoming Tw 41 !!.		
7.8	F.F.Evaps.	US E/Rate 5.4 > 1.4 & flashing over.	
8.8	No.1 M.E.Evap. No.2 M.E.Evap. F.F.Evaps.	Caustic b/out Caustic b/out Caustic b/out f/over on start up. E.S.Tank return line blocked.	
10.8	E.S.Tank return line cleared.		
11.8	No.1 M.E.Evap.	Caustic b/out & gloves etc. removed from Jet Condensor s/ring.	
13.8	No.2 M.E.Evap.	Caustic B/out	
14.8	F.F.Evaps.	Caustic B/out - too short	
15.8	No.1 M.E.Evap.	E/Rate 4.9 s/chest 20 o/head +9	
16.8	No.2 M.E.Evap.	Caustic B/out & dithionite washed. Cond. valve replaced 3/4 Pans. S/Trap fixed.	

17.8	No.1 M.E.Evap.	Caustic b/out & dithionite washed.
	No.2 M.E.Evap.	E/Rate 5 l/Sec.
18.8	F.F.Evaps.	Require Caustic b/out E/R 1.7 & Flashing over.
19.8	F.F.Evaps.	US
20.8	No.1 M.E.Evap.	US s/chest 20 o/head +10
21.8	No.1 M.E.Evap.	Caustic b/out.
	F.F.Evaps.	Require caustic b/out.
22.8	No.1 M.E.Evap.	Caustic b/out but too quick!!
	No.2 M.E.Evap.	Water logged Valving set wrong.
23.8	F.F.Evaps.	Boiled out but too short.
	No.2 M.E.Evap.	Caustic B/out
	No.1 M.E.Evap.	Requires a caustic b/out s/chest 18 o/head p +8

APPENDIX F

SYSTEM EVALUATION BY THE TRAINING CO-ORDINATOR

PULP MILL BUSINESS UNIT
Burnie Mill

MEMORANDUM

5th December 1990

TO: H.W. van Ommen
FR: P.D.Mole

SUBJECT: EVAPORATOR SECTION - EXPERT SYSTEM

COPIES: G.L.Kristensen, P.Crowther, J.E.A.Graves, W.G.Springham, B.Samborski, Pulp Mill Foreman (10), Evaporator Operators (5).

SUMMARY:

The VP-Expert based diagnostic system developed for the Evaporator Section by Mr.Paul Crowther (University of Tasmania Masters Student) is nearing completion. As part of the evaluation process the system has been introduced to Plant Operators and tested against a list of operating problems (and known solutions) from a 4 month survey of the Evaporator Log sheets and the Pulp Mill Foreman Log. The system provided the solution to most of the problems that occurred over that period of time (attached).

The system has potential to be useful tool in trouble-shooting the Evaporator Section and will be a valuable aid in the training of new operators. This is particularly important as the Evaporator Section forms a central part of the career paths planned for the Pulp Mill under restructuring.

For the full potential of the system to be realised as an " on line " trouble shooting aid it needs to be located in the operators Control Room as it is impracticle for operators to use the system in its current location (the Pulp Mill Training Centre).

DISCUSSION:

The system has recently been reviewed by existing plant operators, the Production Superintendent responsible for the area and the Pulp Mill Operations Manager with favourable response from all concerned.

The system has been checked against a list of problems associated with the plant over a 4 month period and if used by operators the system has the potential to reduce soda losses and optimise throughput from the plant which could off set the cost of installing the system.
For example soda losses for the Evaporator Section for Cost Period 5 (4 weeks ended 28th November, 1990) amounted to $121,500, $62,800 of this was attributed to " flash-overs " most of which is preventable or at least can be minimised by corrective action.

As the DARS Plant comes on line the Evaporator Section will again become the "bottle neck" of the Pulp Mill, performance improvements therefore have the potential to give greater cost benefits than that of soda losses as any increase in performance will result in higher pulp output from the Digesters.

The system relies a lot on Operator interpretation of results, readings etc. , to this end instruments around the section will be standardised (at present pressures and vacuum are measured in - "Hg, psi, Kpa and "W.G.) and target values added to the Log Sheet so that a gradual deviation from normal can be detected and acted on quickly.
Operators could then use the system to find the solution to the problem and if this means shutting the system down for maintenance or cleaning then justification for doing so is provided.
For example on the 25th April, 1990 No.2 M.E.Evaporator Surface Condenser vacuum had gradually dropped to -65 Kpa indicating either the vapour side of the condenser was fouled with A.Q. or the water side was fouled with organic slime, it was not until 23nd May that the set was shut down and a dithionite wash (used to remove A.Q. scale) performed. For nearly 4 weeks the multiple effect was running well below its rated throughput. This is 1 of many instances where action should have been taken earlier.

In conclusion I would like to thank Paul Crowther for his time and effort in developing the system which should prove to be a valuable asset to the operation of the Evaporator Section of the Burnie Pulp Mill.

Paul Mole

Paul Mole
Pulp Mill Training Co-ordinator

PDM/pjb
PuP101/90

APPENDIX G
SAMPLE DIAGNOSIS USING THE SYSTEM

The following is a sample consultation for an incident on the 26th April 1990 where the pre-evaporators were flashing over. The critical reading involved here was an incoming liquor density of 20. It will be noted that other information and observations need to be entered by the user.

The consultation is shown in normal text with user menu selections underlined. Comments and explanations are in italics.

EVAPORATOR DIAGNOSTIC SYSTEM

VERSION 1.0

Under normal operation this system will ask about certain key indicators of the evaporators performance. Problems and their solutions will be indicated.
If you want to know why a question is being asked press the / key at any time and select WHY
PRESS ANY KEY TO CONTINUE

After the opening window the system begins asking question to locate the area in which the problem is occurring.

What is the main problem area ?

M E SETS FINISHING PAN <u>F F E</u>

Commencing an investigation of the falling film evaporators. Chaining to the F F E knowledge base. There will be a short delay while it loads. Press return to initiate loading of the knowledge base.

The system goes into a forward chain at this stage loading the falling film knowledge base.

EVAPORATOR DIAGNOSTIC SYSTEM

FALLING FILM EVAPORATOR SEGMENT

The operator is first asked which if any alarms are sounding. He checks the alarm panel to determine this.

Are any of the following alarms active?

INSTRUMENT AIR PRESS	INSTRUMENT POWER
<u>CONDENSATE CONDUCTIV</u>	CONTROLLER ALARM
CONDENSER COOLING	SURFACE CONDENSER
NO ALARM SOUNDING	

The system forward chains again and loads the alarm knowledge base for the falling film evaporators. From this point the system begins backward chaining looking for a value for the problem solution defined by a FIND statement in the ACTIONS or metaknowledge section of the VP-Expert system.

Is the vacuum fluctuating?

The operator checks the Taylor controllers to determine this

YES   <u>NO</u>

What is the incoming black liquor density?

20

At this point the operator wants to know why this question is being asked and presses the /, then F3 key which selects WHY. A window opens and the following message is displayed.

The question is being asked because low liquor density usually indicates pre-evaporators problems. density less than 25 is generally considered low

Press any key to continue

The system then begins an investigation of problems associated with the pre-evaporators

Are the pre-evaporators working to capacity?

YES NO

At this point a rule has all its if conditions fulfilled and the solution appears in a window. If YES had been selected here other features of the pre-evaporators would have been investigated.

The High Condensate Conductivity Alarm is being caused by the low density of the incoming black liquor due to the pre-evaporators not working to capacity. A change over of vessels is required.

a) Reduce the black liquor feed to the pre-evaporators to
5 lt/sec

b) Initiate change over of vessels

c) Select channel 7 on the multi-variable recorder (UR4410)
to display the conductivity reading

d) After change over sequence is complete increase
pre-evaporator steam pressure controller (PIC4430)
set point slowly until the operating pressure of 65 kpa
is reached

e) Increase the post concentrator steam pressure controller
(PIC4431) set point slowly until the operating pressure
of 150 kpa is achieved

f) After the conductivity alarm clears, slowly increase
the black liquor feed flow to the pre-evaporators
(FV4423, FV4424) until the design feed rate of
13 lt/sec is obtained

This consultation took about two minutes. About a minute of that was taken by the knowledge bases being loaded.

After the diagnosis is displayed the system asks if the operator would like to do another investigation of the falling film evaporators. If the answer is no the system cycles back to the first message shown at the start of the consultation.