Optimising Paper Mill Steam and Electricity Generation

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Abstract

Fletcher Challenge Paper owns and operates an integrated newsprint and kraft pulp mill in New Zealand's eastern Bay of Plenty, commonly known as the Tasman mill. The mill has an average electrical load of 170 MW. Three steam drawing turbo-alternators are operated on site, which are able to generate as much as 40 MW. The remaining electricity required is purchased.

Steam Plant operations staff are responsible for managing the supply of steam to the pulp and paper mills, and also internal electricity generation. Operational conditions, such as steam requirements, vary continually. When coupled with varying electricity price forecasts, this fluctuation produces a complicated set of trade-offs.

A decision support tool has been running in the Steam Plant control room since early March 1999. This tool is commonly known as SPOT, or Steam Plant Optimisation Tool. SPOT is a linear program which uses real time operations data, and the latest half-hourly electricity price forecasts to produce an optimal plant operating strategy.

This paper describes the nature of the Tasman Steam Plant operations, the formulation of the SPOT model and a description of its implementation.

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1 Tasman Mill Steam Requirements

Steam is essential at Tasman for a number of processes, with the main requirement being drying of pulp and paper. Average demand is about 250 tonnes per hour of 3.4 barg steam, and 130 tonnes per hour of 10.2 barg steam.

Steam is supplied from a number of sources – a simplified diagram is shown in figure one. Two chemical Recovery Boilers burn spent chemicals from the kraft pulping process, recovering expensive chemicals, and also producing around 190 tonnes per hour of high pressure (44 barg) steam. Two waste wood/oil fired boilers produce up to 130 tonnes per hour of 44 barg steam. A geothermal field located nearby delivers around 270 tonnes per hour of 7 barg steam.

The 45 barg steam produced in the boilers is delivered to a common header. The 45 barg steam is then reduced in pressure to provide process steam at 10.3 barg and 3.4 barg for the pulp and paper mills. The balance of 3.4 barg steam is produced in heat exchangers, utilising geothermal steam.

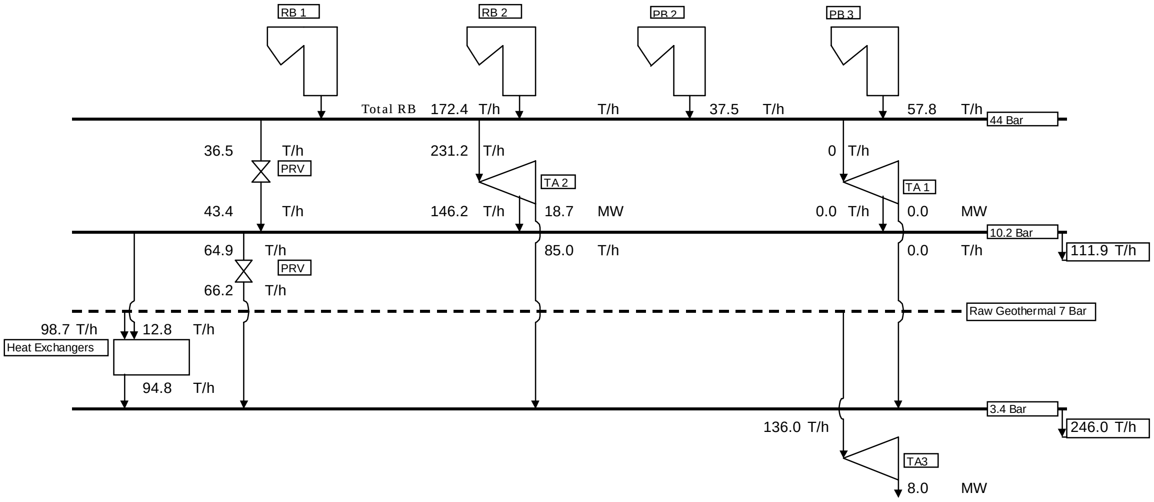


Figure One – Tasman Mill Steam System

Pressure reduction can take place in the mill’s two turbo alternators whilst producing power, or passing through pressure reducing valves, or a combination of both depending on the process steam demand.

The turbine control system incorporates two pressure controllers. One to control the passout pressure (10.3 barg) the other to control the exhaust pressure (3.4 barg). The outputs from the pressure controllers are interlinked to provide turbine stability when there is a change in demand in either process steam main.

The final process steam temperature is controlled by adding water through desuperheating stations at selected points in the steam mains. This process also adds to the total mass of steam produced.

The geothermal steam is utilised in five heat exchangers, which produce 3.4 barg process steam, direct in the process (Recovery Boiler area) and boiler feedwater heaters.

The remaining steam is passed through a turbine which has a number of functions:

1. Electrical power generation (8 MWhr max.)
2. The exhaust is utilised in a liquor pre-evaporator, water heater and foul condensate stripper.
3. The turbine has control systems, which stabilise the pressure of the incoming geothermal steam to the mill.

The two power boilers are primarily fired with waste wood (hog) as fuel. Provision to fire fuel oil is provided for boiler start-ups, and in the event of insufficient woodwaste being available due to supply problems. Also at times the moisture content of the woodwaste requires auxiliary fuel to be burnt to stabilise the combustion process.

1.1 Turbine Operations

Turbo Alternators One and Two use high pressure (45 barg) steam to generate electricity. Steam can be passed out after the first stage of the turbine at 10.2 barg, and all remaining steam is exhausted at 3.4 barg.

The amount of 45 barg steam used varies, depending on how much electricity is generated, and how much steam is passed out. The operating range of Turbo Alternator Two is shown in the figure two below. TA1 has a similar performance curve. The turbines can operate anywhere within the highlighted portion of the curve and therefore are solely dependent on the mill's steam demand for the amount of electrical power that can be produced.

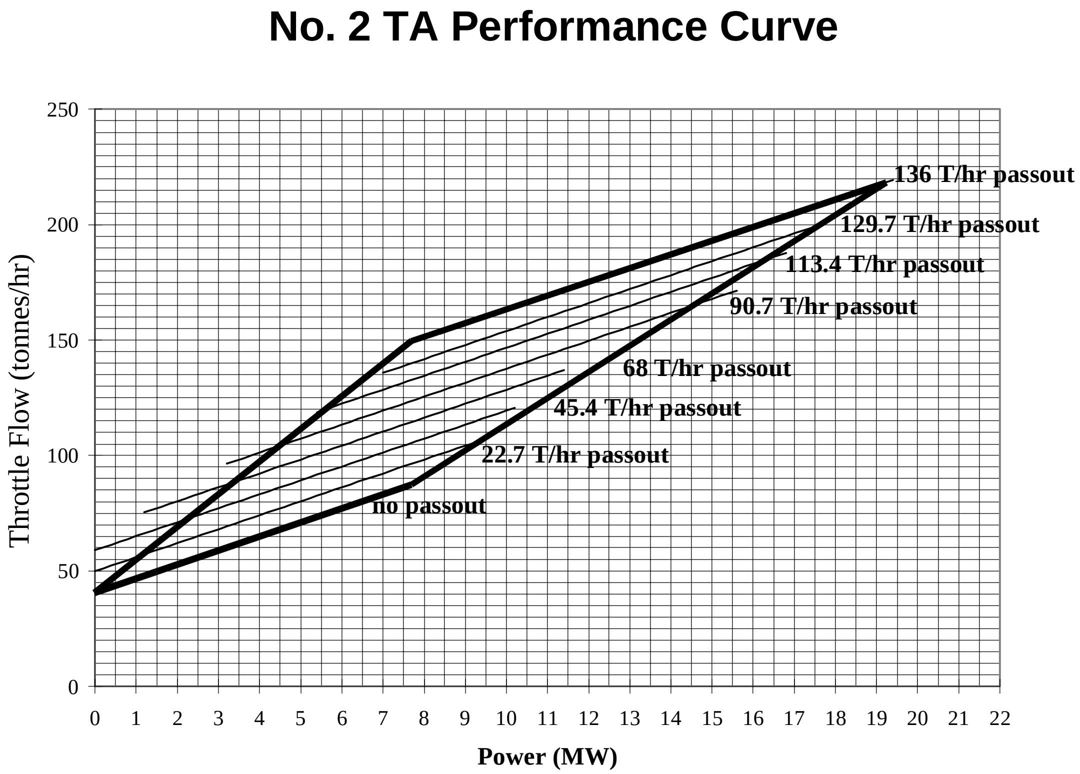


Figure Two – No 2 Turbo-Alternator Operating Range

1.2 Steam Plant Operational Requirements

The main function of the Steam Plant is to supply steam to the pulp and paper mills. A secondary function is utilisation of surplus steam to generate electricity for internal use. At any time there are a number of alternative options for achieving these two functions. It is obviously desirable to choose the lowest cost option.

Factors which influence steam plant costs include:

- cost of fuel oil
- moisture content of the waste wood fuel, which is stored in the open
- the spot price of purchased electricity at any time
- process demand for steam
- availability of recovery boiler steam

- availability of geothermal steam
- cost of imported hog fuel
- maximum site electrical demand – which is used to calculate lines charges

A decision support tool has been developed which provides operators with instant analysis of the current plant operating conditions, and produces an optimal operating strategy. This tool is named the Steam Plant Optimisation Tool, SPOT for short.

SPOT is a linear program whose objective is to find the lowest cost way of meeting the mill's steam and electricity requirements. It has been running in the control room since early March 1999.

2 Formulation of SPOT as a Linear Program

Initially SPOT was developed in the AMPL mathematical programming environment using the CPLEX LP solver, both available from ILOG. Once proven the equations were translated into a similar model in Microsoft Excel, using a solver from Frontline Systems. A user-friendly front end has been developed and a number of software switches have been provided to override the underlying constraints, when appropriate.

The reason the platform was switched from AMPL to Excel was primarily the need for real-time process data. Tasman has a mill-wide information system called PI (Plant Information, available from Oil Systems International). Data is continually supplied to PI from the many control systems on site. A useful add-in has been developed for Excel, which allows data to be quickly downloaded from PI. Electricity price forecasts are published every half-hour by the New Zealand Electricity Market. These dispatch prices are stored in the PI database, and are thus readily available via Excel.

The units of all costs and consumptions in SPOT are per hour of plant operation.

2.1 Objective Function

The objective of SPOT is to minimise the cost of supplying the mill with steam and power, which is simply:

Minimise Cost =

*Hog Fuel Cost * Amount of hog fuel burnt*
\+ *Oil Cost * Amount of oil burnt*
\+ *Geothermal steam cost * Amount of Geothermal steam used*
\+ *Purchased electricity cost * Amount of purchased electricity*

Note: The fixed costs of running the steam plant are included in the model, but at this stage have been assigned zero costs. Recovery Boiler steam is available at zero cost.

2.2 Constraints

The main constraints, required to accurately represent plant operations, are briefly described below. For a more complete mathematical description please refer to previous work [1]. Real time data (steam demands etc) is sourced from the PI system.

Steam Demands Must Be Met

Steam is required for the paper machines mainly at 3.4 barg, and mainly at 10.3 barg for the pulp mill. SPOT must satisfy these demands using exhaust and pass-out from the turbines, geothermal steam and steam from the pressure reducing valves.

Electricity Demand Must Be Met

The mill power requirements must be met – either by internal generation, or by purchasing power from the national grid.

Power Boiler Operations

Both boilers can utilise hog (waste wood) and oil as fuel, either separately or concurrently. Minimum steaming rates are applied to maintain stable combustion at all times (unless a boiler is taken off-line). The amount of steam able to be produced is proportional to the calorific value of the hog fuel and oil mix being burned at any time.

Geothermal Steam

Geothermal steam is either used in number three turbine, or passed through the heat exchangers, or a combination of the two. The amount of steam available at any time is limited.

Whenever TA3 is operating there is a requirement in the plant for approximately 95 tonnes per hour of exhaust to be used elsewhere on the mill site (for the hot water heaters, foul condensate system and liquor pre-evaporators). This requirement is handled in SPOT by allowing the first 95 tonnes per hour of steam through TA3 to be at zero cost.

The heat exchangers essentially convert raw geothermal steam from the steam bores at 7 barg into clean 3.4 barg process steam. The efficiency of the heat exchangers is not linear, but it is sufficient for modeling purposes to approximate the efficiency as a series of piece-wise linear functions.

A small amount of 10.3 barg steam is injected into the outlet stream of steam from the heat exchangers in order to maintain sufficient enthalpy of the process steam.

Marginal Cost of Hog Fuel

A certain amount of hog fuel is generated on site in the woodyard. Additional hog fuel is brought in from surrounding saw mills. With higher volumes needed the hog must be transported from sawmills which are further away, thus increasing the cost. This marginal cost of hog fuel is included in SPOT as a series of cost constraints.

Turbo Alternator Operations

Equations have been included which define the operating region of the three turbo alternators. Furthermore practical experience has shown that the operating regions are somewhat different from the original specifications and additional constraints are required to reflect the range of exhaust which is actually achievable. These are shown as the bold outlines in figure one.

Pressure Reducing Valves

Steam can be converted from higher pressure to lower pressure through de-super heating pressure reducing stations. The first reduction is from 45 barg to 10.3 barg, the second from 10.3 barg to 3.4 barg. The effect of adding water to the steam is accounted for.

Additional Constraints

Further constraints, that will not be listed here, are included in SPOT to provide:

- Additional process detail
- Ability to switch on and off various sections of plant
- Alter some process parameters
- What-if analysis

3 SPOT Implementation

The development and implementation of SPOT is quite a long story, which has not yet reached a point of ultimate conclusion.

3.1 Origin of SPOT

The initial idea for optimising internal electricity generation arose from several conversations at the Tasman mill in 1997. A major catalyst was a coincidental mill tour by a group of students and lecturers from the Auckland University Engineering Science Department. From these apparently disparate events a project, of sorts, commenced.

3.2 Management Acceptance

With the support of a few individuals the author developed a prototype model in AMPL. This prototype model did not contain enough detail to produce particularly sensible solutions, and as a result suffered from an initial lack of credibility amongst mill management. However a few optimists gave the project their support, and gradually the model acceptance increased. It was necessary to work very closely with Steam Plant process experts to ensure that the complicated steam flows were incorporated correctly, and that any approximations used were necessary, and sensible.

An iterative approach was taken over a period of months – adding details one by one until the solutions were consistently sensible, and operationally feasible.

Once the model was transferred to the Excel platform the opportunity was taken to incorporate a number of helpful features, such as graphs, process diagrams and using archived data to reconstruct a past scenario.

Prior to implementation in the Steam Plant Control Room an in-depth verification program was initiated to ensure the results from SPOT were correct, and also to provide a benchmark for future evaluation of its effect. SPOT was run automatically every half-hour for some weeks. Actual plant operating data was logged with corresponding SPOT data. The average difference between the actual plant operating costs and the SPOT operating costs was determined. The results showed an opportunity for significant reductions in operating costs.

At this point, not surprisingly, tremendous support was provided from mill management.

3.2 Operator Acceptance

An incentive was deliberately provided for the operators to ‘beat SPOT’. It was hoped that their competitive nature would encourage them to outwit the computer, and thereby reduce costs even further. For instance, the maximum output from Turbo Alternator Two is limited to 18.7 MW in SPOT, which is it’s design rating. Under some conditions it is actually possible to generate 20 MW from this turbine. Also, the actual steam flows vary somewhat due to the inherent flow meter variations. The implications of this are that at times SPOT requires slightly more 45 barg steam than the actual values (from PI) to meet the mill’s steam demands.

Immediately prior to implementation in the Steam Plant control room a number of senior operators were provided with an overview of SPOT, and training as to its use. Documentation was also provided to help people navigate the screens, and use SPOT. Several individuals supported operators with their use of SPOT, working alongside them in the control room.

The initial responses were fairly reflective of each individual’s personality, and ranged from support to derision. Feedback was freely provided, mostly pointing out how SPOT was in fact unrealistic.

Once again an iterative approach was taken; incorporating the issues raised one by one until no outstanding issues remained. During this process SPOT experts sat in the control room regularly for a period of a couple of months, attempting to not only correct the inaccuracies which lingered in SPOT, but also to develop good working relationships with the Steam Plant Operators.

It needs to be pointed out that Steam Plant management preferred not to take an autocratic approach with the implementation of SPOT. Their view was that such an approach would not achieve long term objectives of ongoing cost reductions. It was preferred that operators would choose to use SPOT of their own accord, thereby gaining increased job satisfaction, as well as achieving management cost reduction objectives.

At the time of writing it is apparent that SPOT has, for the most part, indeed brought about changes in attitudes and operational habits. Good cost reductions are now often being achieved.

3.3 Next Steps

However a major issue remains, which reduces the amount of time SPOT is utilised. SPOT resides on a PC in the control room, which is physically separate from the Distributed Control System (DCS) operating screens. The present version of SPOT requires operators to initiate, before it will update data and re-solve. At times the operators are too busy with the operational functions of their job to have time to concentrate on using SPOT.

They have suggested a remedy for this situation, which is to have SPOT information displayed on their DCS screens. This simple request poses a number of technical challenges, most brought about because of the mill's policy of not allowing data to be transferred from the mill network to the DCS network. All the data is available on the DCS loop, apart from electricity price forecasts. These prices are said to pose even more of a threat to mill network security, as they originate, for all intent and purposes, from the Internet. A technical solution has been identified, and will shortly be implemented.

4 Conclusions

The development and implementation of SPOT has been a very successful exercise. Operators now have a tool that allows them to make optimal decisions regarding the running of the Steam Plant. To date a substantial amount of cost savings have been achieved. Still more cost savings are possible, once SPOT is incorporated in the Steam Plant DCS system.

SPOT has also been an interesting exercise in implementing operations research in an operating environment. This project has demonstrated three major elements of success in industrial Operations Research. The first being identification of a project which would benefit from mathematical modeling. The second is successfully modeling the process. The third is implementing the model, and ensuring that it is used.

It is the experience of the author, that the third element of implementation is by far the most important, and also the most difficult, and essentially determines the success of the whole exercise.

5 References

[1] G.R. Everett and G.W. Hotson, "Steam Plant Optimisation Tool", Proceedings of APPITA Conference, 1999.

6 Acknowledgements

The author wishes to thank Joe Hotson, whose knowledge, time and infinite patience are a major reason for the success of SPOT.
The author also wishes to thank Andy Philpott, for his advice and help.

7 Appendix

Three examples of SPOT screens are included here.

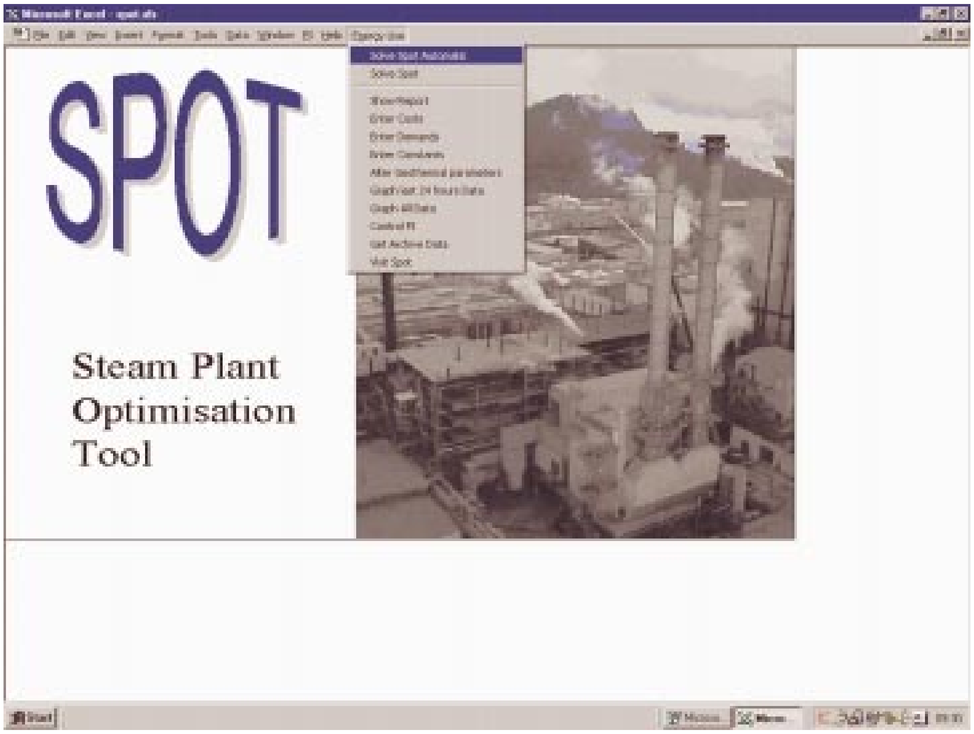


Figure Three - Main SPOT Menu

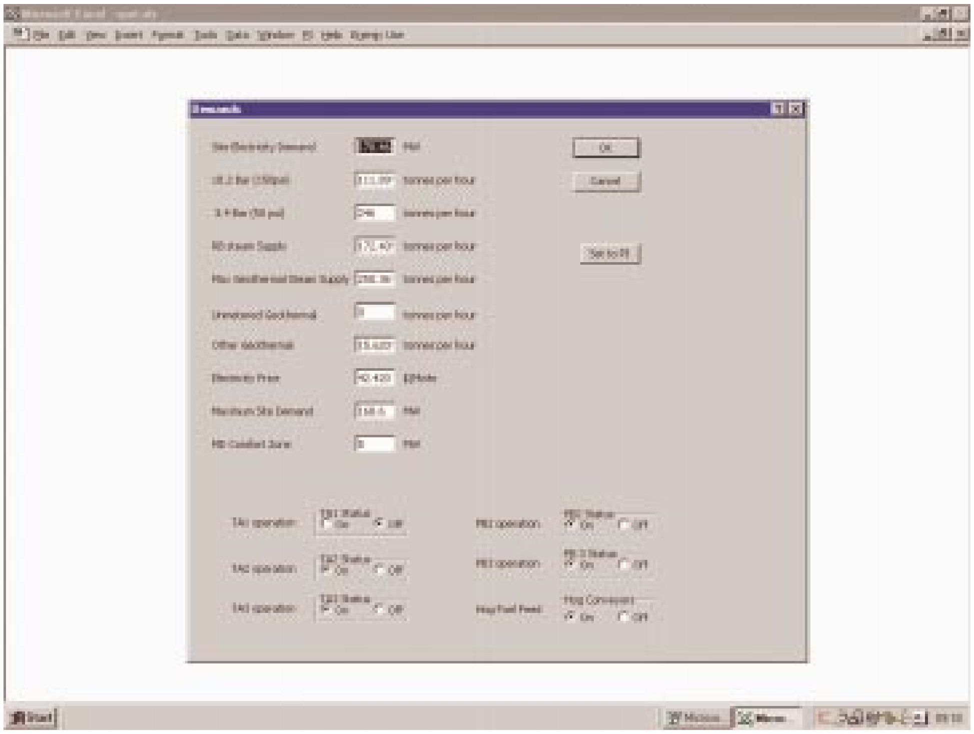
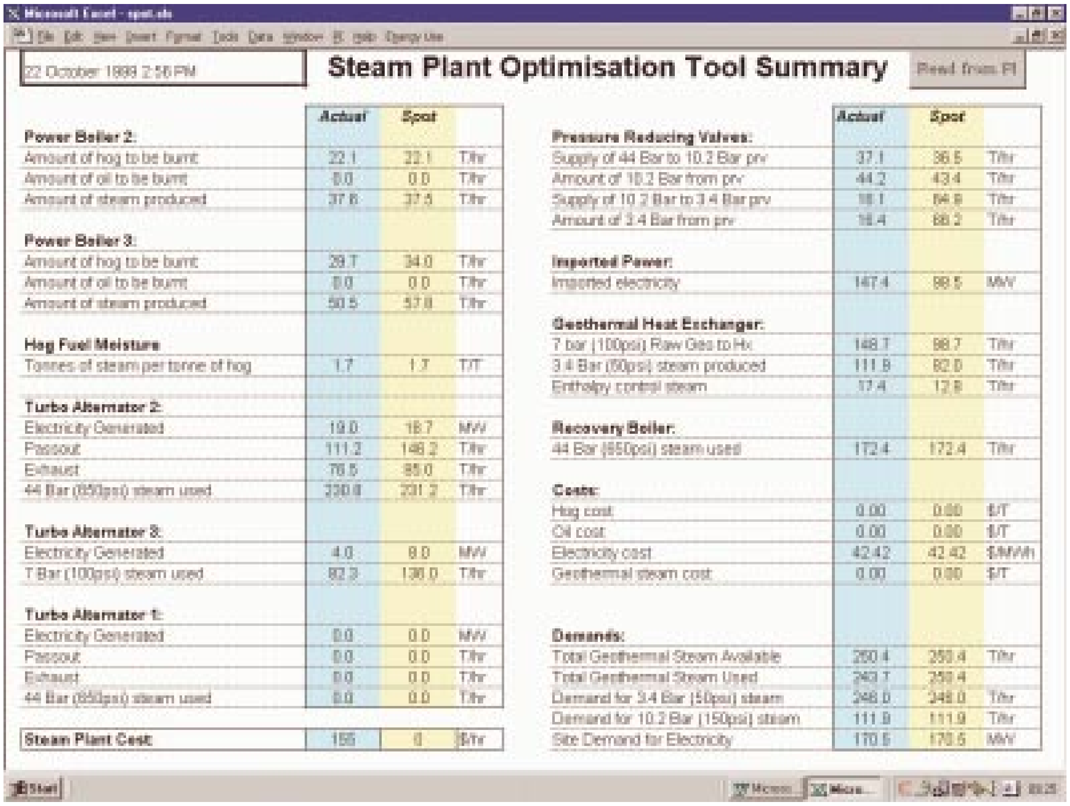


Figure Four - Entering Demands, and altering plant configuration



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Steam Plant Optimisation Tool Summary

	Actual	Spot	
Power Boiler 2:			
Amount of hog to be burnt	22.1	22.1	T/hr
Amount of oil to be burnt	0.0	0.0	T/hr
Amount of steam produced	37.6	37.5	T/hr
Power Boiler 3:			
Amount of hog to be burnt	29.7	34.0	T/hr
Amount of oil to be burnt	0.0	0.0	T/hr
Amount of steam produced	50.5	57.8	T/hr
Hog Fuel Moisture			
Tonnes of steam per tonne of hog	1.7	1.7	T/T
Turbo Alternator 2:			
Electricity Generated	19.0	18.7	MW
Passout	111.2	146.2	T/hr
Exhaust	78.5	85.0	T/hr
44 Bar (650psi) steam used	230.8	231.2	T/hr
Turbo Alternator 3:			
Electricity Generated	4.0	8.0	MW
7 Bar (100psi) steam used	82.3	136.0	T/hr
Turbo Alternator 1:			
Electricity Generated	0.0	0.0	MW
Passout	0.0	0.0	T/hr
Exhaust	0.0	0.0	T/hr
44 Bar (650psi) steam used	0.0	0.0	T/hr
Steam Plant Cost:	155	0	$/hr

	Actual	Spot	
Pressure Reducing Valves:			
Supply of 44 Bar to 10.2 Bar prv	37.1	36.5	T/hr
Amount of 10.2 Bar from prv	44.2	43.4	T/hr
Supply of 10.2 Bar to 3.4 Bar prv	18.1	84.8	T/hr
Amount of 3.4 Bar from prv	18.4	88.2	T/hr
Imported Power:			
Imported electricity	147.4	98.5	MW
Geothermal Heat Exchanger:			
7 bar (100psi) Raw Geo to Hx	148.7	98.7	T/hr
3.4 Bar (50psi) steam produced	111.9	82.0	T/hr
Enthalpy control steam	17.4	12.6	T/hr
Recovery Boiler:			
44 Bar (650psi) steam used	172.4	172.4	T/hr
Costs:			
Hog cost	0.00	0.00	$/T
Oil cost	0.00	0.00	$/T
Electricity cost	42.42	42.42	$/MWh
Geothermal steam cost	0.00	0.00	$/T
Demands:			
Total Geothermal Steam Available	260.4	250.4	T/hr
Total Geothermal Steam Used	240.7	250.4	
Demand for 3.4 Bar (50psi) steam	248.0	248.0	T/hr
Demand for 10.2 Bar (150psi) steam	111.9	111.9	T/hr
Site Demand for Electricity	170.5	170.5	MW

Figure Five - Main Report