Computer Applications and Decision Support System for efficient Management of Process Industries.

THESIS
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By

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CERTIFICATE

This is to certify that the thesis entitled " ***Computer Applications and Decision Support System for Efficient Management of Process Industries*** " and submitted by *G.Govinda Rajan*, *ID.No. 91 PHXF 404* for award of **Ph.D. Degree** of the Institute, embodies the original work done by him under my supervision.

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List of Abbreviations

AAA	: Ambient Air Act
4 M's	: Men ,Machine ,Materials ,Money
CAA	: Clean Air Act.
CV	: Calorific Value in kcal/kgm
DIDC	: Distrbuted Digital Control
DSS	: Decision Support System
EA	: Environment Act
EPA	: Environmental Protection Act
HHV	: High heating value
HRM	: Human Resources Management
Hy.Distillate	: Heavy distillate
Info	: Information
IIS	: Integrated Information System
LAN	: Local area network
LHV	: Lower heating value in kcal/kgm
LP	: Linear Programming
LPG	: Liquified Petroleum Gas
Lt.Distillate	: Light Distillate
MIS	: Management Information System.
Mid Distillate	: Middle distillate
Misc	: Miscellaneous
NLP	: Non Linear Programming
NOx	: Nitrogen Oxides (pollutant)
O & M	: Operations and Maintenance
PFL	: Plant fuel and loss
SPM	: Suspended Particulate Matter (pollutant)
WAN	: Wide area network

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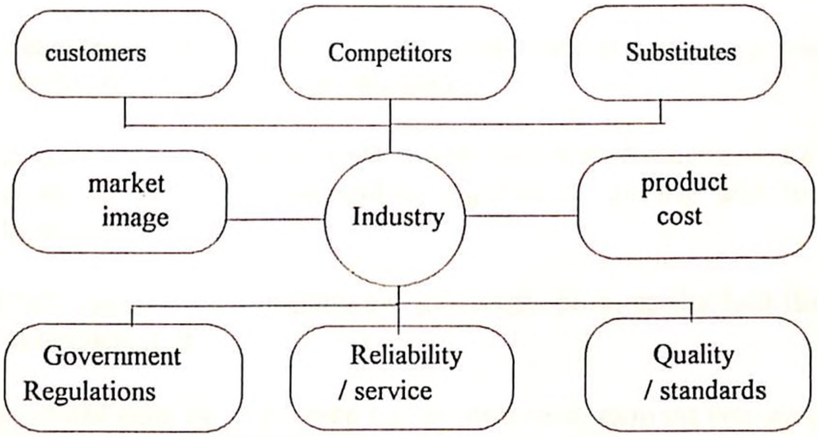
Introduction

1. Introduction

This research work basically identifies the need for introducing Computer Application situations in process industries and the nature and scope of computer application areas of resources management which vary from industry to indusrty. Since all these resources are inter related ,evaluation of various mixes could be carried out using computer programs and EORT techniques. Industry is not an island itself. A hierarchial relationship exists between the industry and the environment as shown below in *fig 1.01. (Ref 1,3)*

fig 1.01. Factors affecting industrial performance



In this Research Work , certain performance monitoring programs have been developed using simple programming languages like GWbasic ,Dbase ,Lotus, Foxpro etc . The emphasis is on 'simplicity , user friendliness & accuracy ' *(Ref 4,5).*

Certain live cases are also analysed using the decision models .Statistical parameters developed by them are tested by ' what-if ' analysis in selected cases . The programs developed in the process of Research could serve as Decision support system for executives at various levels and other users . This approach could be used effectively to analyse process industries like petroleum , petro chemical and fertilizer industries .The emphasis is basically on development methodology of performance monitoring targets within the imposed constraints using quantitative techniques , statistical and mathematical models.

Background of the research:

Current competitive industrial scenario of our country warrants efficient performance at all levels and most of the decisions are influenced by external factors such as cost of raw materials , availability, substitutes , cost of utilities , man power, wastages etc .This has virtually led every top executive to a *dynamic decision making* *situation* and more frequent strategic planning is required than in the past. Since the constraints imposed have varying degrees of influence on productivity and profitability 'Computer aided decision support system' is considered indispensable in such complex situations .

Following factors explain the need for using performance indicators for the industry.

* Transition from 'sellers' to a 'buyers' market implies that customer demands have to be met more satisfactorily, not only in respect of the product, quality and price but also in a positive way through delivery time and reliability. Logistics has hereby become an essential part of the marketing function.

* A continuous shortening of the life cycle of products and therefore a growing pressure on lead time in development and production.

* Increasing competition in the industrial world which is characterised by increased efforts in meeting the customer's demand at ' right time , quality and cost ' which is the secret of business success .

These three changes in the company environment point to the fact that LOGISTIC PERFORMANCE IS ESSENTIAL.*(2)*

This insight could now be supported by integral management concepts and philosophies comprising of the following planning activities.*(2,4)*

1.Manufacturing Resource Planning (MRP)
2.Distribution Resource Planning (DRP)
3.Optimised Production Technology (OPT)
4.Just-in-Time (JIT)

Application of these concepts became possible by the development of available tools (computers and software) which serve to increase the effectiveness and efficiency of the integral logistic route.

Performance monitoring of the resources, i.e four M's of management is very essential for every industry. When the industry is complex monitoring the performance becomes more difficult and many top executives frequently resort to the 'rule of thumb ' or 'specific consumption ' parameters . Targets are monitored by the executives as to how much should have been the consumption of feed stock , energy , consummables etc for the observed level of activity .

Conventional performance monitoring system adapted in the past by business executives used to be more on '*specific consumption of resources* ' .This was acceptable to many and a single performance target was used as a '*performance indicator* '.

This age old technique of constant targets *irrespective of the quality and quantity of inputs and outputs is superceded by the 'dynamic targeting ' or 'flexi targeting ' technique (32, 59). By flexi target methods ,productivity of any enterprise may be improved further, as against constant target methods , because of the fact that reasons for performance variations could be pin-pointed with accuracy by appropriate models for remedial action .* In complex petroleum , petro chemical and fertilizer industries where huge quantity of cost intensive resources are consumed , this control technique is very imperative.This research focusses on the design of modern performance evaluation models .

Process Industries are no longer monopolistic and due to technological development all industries are facing serious competition from within and also from outside. In globalisation scenario, Demand-Supply position for products and services are also highly dynamic. These conditions warrant fast decisions to be taken by the executives in respect of feed stocks, feed mix , process mix, feed rate , type of operation to be adopted etc. Hence there exists a dire need to adopt computer-aided management system at all levels for successful management of the process industry.

Following the economic situation of the worldwide industries and the hectic competition industries are facing, integration of the economic facets of the micro level process units for optimisation and control has become the fundamental objective. *Each industry has to manage it's resources judiciously and encounter the competition with calculated risks. The complete processing chain from the field to the final management involves taking decisions of some form or other at various levels.* Unless the decisions and the actions taken by the managers at various levels are in the unified direction , the organisation is likely to face crisis .A good communication system is very imperative for achieving organisational objectives .

Decision Support System
for Unity of Direction:

Every section head of the organisation needs to take certain decisions related to his section of the organisation. Some of the Decisions may be very critical and crucial while others may be conventional / structured decisions (*1,4*). Unless the decisions taken at each section or sub-section are in unison with the organisational objectives, there is likely to be a very conflicting situation in the enterprise at all levels.

This could be averted only when the decisions are understood clearly by each concerned supervisor and the executing authority in unambiguous terms for implementation. For arriving at such decisions at each level , a Decision support system is very important. From managerial point of view, these Decisions may be further broken down into

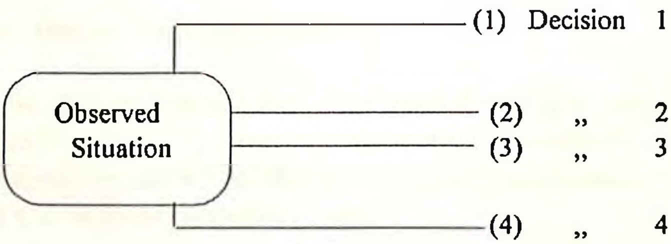
*Routine Decisions
*Structured Decisons
*Non-routine Decisions
*Emergency decisions etc.

Example of routine decisions are

* throughput reduction when product inventory piles up
* reducing steam load by consumers when a boiler fails.
* reducing water consumption, when the water supplies are inadequate etc.

Structured Decisions are those where, the decision making authority will stipulate certain conditions for taking each decision route for implementation. A typical example related to operation of a distillation unit is given below in *fig 1.02.*

fig 1.02. Decision Making Situations



As could be seen from the above diagram, when situation 1 exists, decision 1 will be followed , while situation 2 exists, decision 2 will be followed and so on .These could be converted into decision rules and procedures for effective implementation by the authorised executives of the operation . From this it is obvious that Decision making situation arises very frequently in an organisation and for taking the 'right decisions at the right time' , a good amount of information is required by the executives. In dynamic situations, more 'apt' and accurate information is the basic requirement for taking appropriate decisions.

Under these situations, only a good 'decision support system' could be used effectively by each one to achieve ***'organisational productivity'***.

Lack of this information could even lead to *'organisational disaster'* depending on the type of industry and it's financial strength. In fact it has been observed that many *sick industries, are the victims of poor information system*.

This thesis essentially covers planning, organising and designing of Decision Support System under various decision - making situations, impact of parameters, modelling methodology, implementation of DSS and monitoring. This approaches the 'managerial ' problems by computer-aided techniques and information theory. Certain cybernetic control models are also covered in the thesis.

The basic objective of management is ***'optimal utilisation ' of resources*** to create an economic activity which will increase the profitability of the enterprise. The resources are ***'men','machines', 'materials', 'money' and 'management'*** each having certain monetory value. Hence an optimal management of these resources is imperative to achieve 'high productivity'.

While a number of managerial styles are followed by different managers, quantitative managerial techniques using the latest operational simulation analysis, Evolutionary operations Research *(7,35)* etc are found to be more scientific and proven and could be adopted by all. This is very much in line with ' F.W.Taylor's scientific management theory .

Work Done by other researchers:

Though substantial work has been done by a number of researchers in the area of DSS related to resource management, most of them are conceptual frameworks or mental models that developers and practitioners use to organise their thinking and guide there activities.*(45)*

A popular conceptual framework for DSS evolved from IBM Research Laboratory in San Jose, California during 1970s.These works were basically done by *Sprague, Ralph.H and Eric Carlson* and presented in the book *'Building Effective Decision Support Systems '*, Englewood Cliffs,N.J, Prentice Hall 1982. Sprague, Ralph H further developed a framework for the development of DSS , and published in MIS Quarterly, 4, No 4 (1980) 1-26.

Some of the key concepts include the following

1.The technology for DSS must consist of three sets of capabilities in the area of *dialog, data and modelling , called DDM paradigm.* A good DSS should have a balance among the three capabilities . It should be *easy to use* to support the interaction with non-technical users, it should have an *access to a wide variety of data* and it should provide *analysis and modelling* in a variety of ways. Many systems claim to be DSS when they are strong in only one area and weak in the others.

2.Three levels of technology are useful in developing a DSS.They are *Configuring DSS tools, DSS generator and Specific DSS.*

3.Effective development of DSS requires an organisational strategy to build an environment within which such systems can originate and evolve. The environment includes *a group of people with interacting roles , a set of hardware and software technology and a set of data resources.*

Related Developments: (45)

Various views have been expressed by manager's on how a DSS should be , as given below.

1.A DSS should provide support for decision-making , but with emphasis on semi structured and unstructured decisions.

2.A DSS should provide decision making support for managers at all levels , assisting in integration between the levels whenever appropriate.

3.Keen and Hackathorn , *'Decision Support Systems and Personal Computing '*, Dept of Decision Sciences, Wharton School ,University of Pennsylvania, working paper 79-01-03, Philadelphia, April 3, 1979, explore three decision types as

Independent , Sequential Interdependent and pooled Interdependent .

4.A DSS should support all phases of the decision making process. A popular model is given by Herbert Simon in his paper , *'The New Science of Management Decision '*, New York,Harper and Row, 1960.

5.A DSS should support a variety of decision making processes but not be dependent on any one.

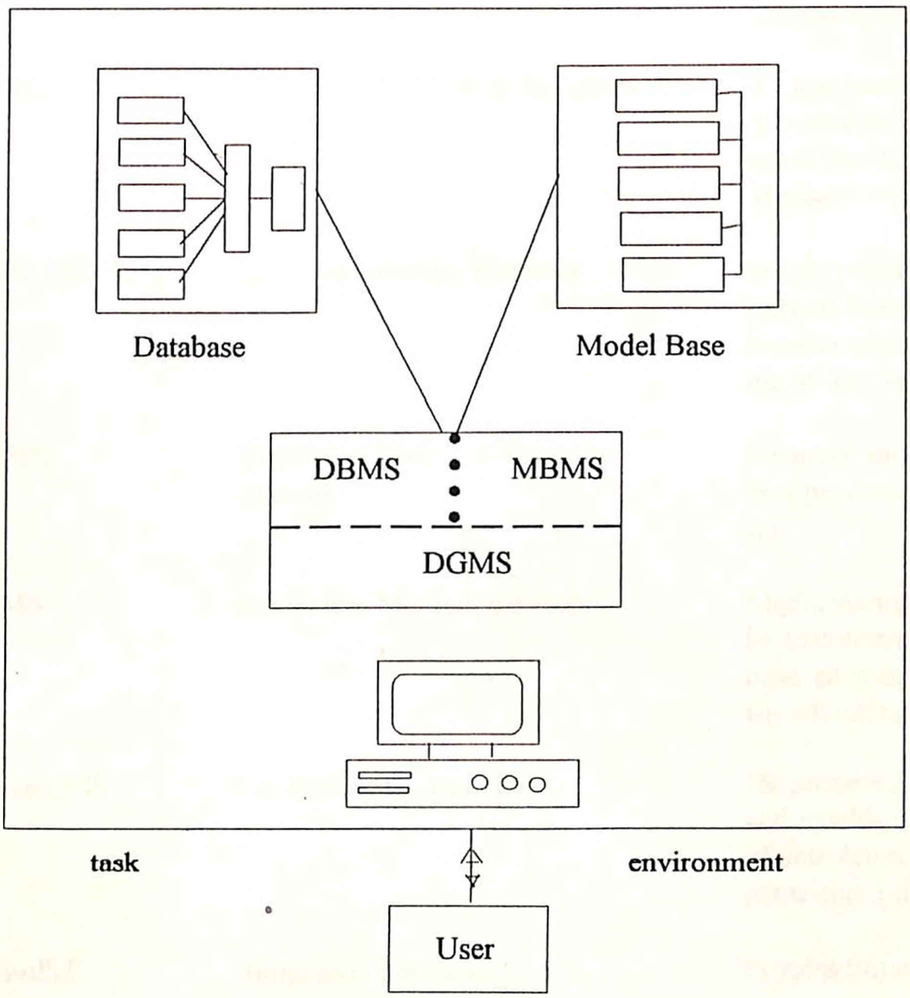
6.A DSS should be easy to use.

Builder's View: Technical Capabilities.

A DSS combines the capabilities of computer based tools and techniques to provide the decision support required by the manager(*s*). Though many of the commercially available software may be used for DSS, it is generally more efficient and effective to use a DSS generator for this task. (*45*)

The components of a DSS are shown below in *fig 1.03.*

Fig 1.03 Components of the DSS



DBMS : Database Management Software
MBMS: Model base Management Software
DGMS: Dialogue Generation and Management Software.

A number of DSS applications have been developed in the past. Some of them are listed below.

Name	*Expansion*	*Applications*
1.GADS	Geodata Analysis Display System	ability to look at more alternatives, improve -ed decision.
2.PMS	Portfolio Management System	Investment decision support system.
3.IRIS	Industrial Relations Information	Ad hoc access to em -ployee data for analy -sis of productivity & resource allocation.
4.PROJECTOR	Strategic financial Planning	insight into the dyna- mics of business and broader understand- ing of key variables.
5.IFPS	Interactive Financial Planning System.	Financial modelling, new product analy- sis.
6.IMS	Interactive Marketing System.	Media Analysis of large consumer data base, plan strategies for advertising.
7.Design II	Chemshare Corporation	for process design and trouble shooting of petroleum and petro chemica unts.
8.SimSci.	Simulation Science	Process Simulation.
9.HySim	Hydro Carbon Simulation	„

10.CHEOPS	Chemical Engg Optimisation Systems	Shell Development Co,USA
11.CHEVRON	General heat and material Balancing System	Chevron Research Co, USA.
12.SCOPE (66)	Sizing and Costing of Process Equipment.	Imperial Chemical Industries,UK.
13.PACER	Process and Case Evaluator Routine.	Dartmouth College, USA.
14.CHESS	Chemical Engg System Simulator	University of Houston, USA.
15.SPEED-UP	Simulation Program for the Economic Evaluation and Design of Unsteady State Process.	Imperial College, London.

(*Ref: 45,16*)

While the first six numbers (1 to 6) given above are used as DSS for general managerial decisions, programs numbered 7 to 15 have specific applications and the users will have to be thoroughly conversant with the program for successful simulation of results . Being specialised programs, common users invariably find it difficult to use the above programs. These programs function in design mode. i.e. The output is specified and the inputs are evaluated by process algorithms . But in real life situation , inputs are known and the output has to be evaluated to determine the process efficiency or performance of the system so as to take appropriate corrective measures.

Objective of current Research : All the DSS systems given above are not generic and are found inadequate to meet the current DSS level due to the dynamic decision - making situation, faced by various types of managers. *Number of monitoring parameters technical , non technical , economic and non-economic for the industry has increased tremendously compared to the past* .Effective decisions can be made only by appropriate technical and non-technical data .The decision support system has to be more precise and exact and should cover all the constraints and limitations. The DSS evolved must cover all the stipulated parameters and increase the net cash-flow, performance and profitability of the industry.

Under these conditions, Scientific Modelling using EORT ,OSA , Logistic and other techniques is imperative. With the advancement of computer aided manufacturing and advanced controls using Distributed Digital Control System, 'dynamic modelling process ' has been simplified. Further, model validation has also become simpler.

This thesis , related to a major refining industry covers general methodology of

a.Model development for the industry covering all activities.
(which is system specific).
b.Selection of combination of parameters that affect the performance
c.Using these parameters in the models for monitoring purpose and .
d.Carrying out 'what-if' analysis to determine the course of action
e.Fine tuning and model validation to reduce the deviations.

Suitable live data have been used wherever possible to high light the impact of various decision routes on productivity and profitability .

The research aims at developing the monitoring system for *'efficient management of process industries '* and could be applied to any industry as the approach is systematic and covers the entire spectrum of activities by an *integrated information system* **(IIS)** .

Information flow for Decision Support System

Chapter 2. Information Flow for Decision Support System to improve Managerial Productivity

Productivity of an enterprise, in competitive situations could be maintained high only when 'right decisions are taken at the right time' and indecisions are avoided.Productivity of the total enterprise comprises of 4 'M's of management namely **men,machine,materials and money** to be managed at all levels. The basic decision support system for the enterprise should cover the information pertaining to the above resources for necessary action.

Information pertaining to the above may be classified and represented by a cybernetic model to explain this concept. The controllable resources are as given in **fig 2.01** for which a computerised system could be of immense help (*1,24*) .

Concept of Productivity Analysis and Control:

Any system *(e.g. process unit ,power plant)* which comprises of sub systems (individual units / processes) and elements (equipments) deploy only the above resources *(i.e. 4 M's of management)* to produce products and / or services. Hence for effective management of the total system , resources consumed in each section must be monitored so that the ultimate *system efficiency* will improve automatically.For achieving this, certain monitoring parameters may be developed for each section as given in *fig 2.01* which could be used to understand whether or not the total system is working efficiently for remedial action .

For developing these performance indicators, certain information is required on a continuous basis. From productivity point of view, the total cost of the resources mix must be minimum per unit output of the product produced.

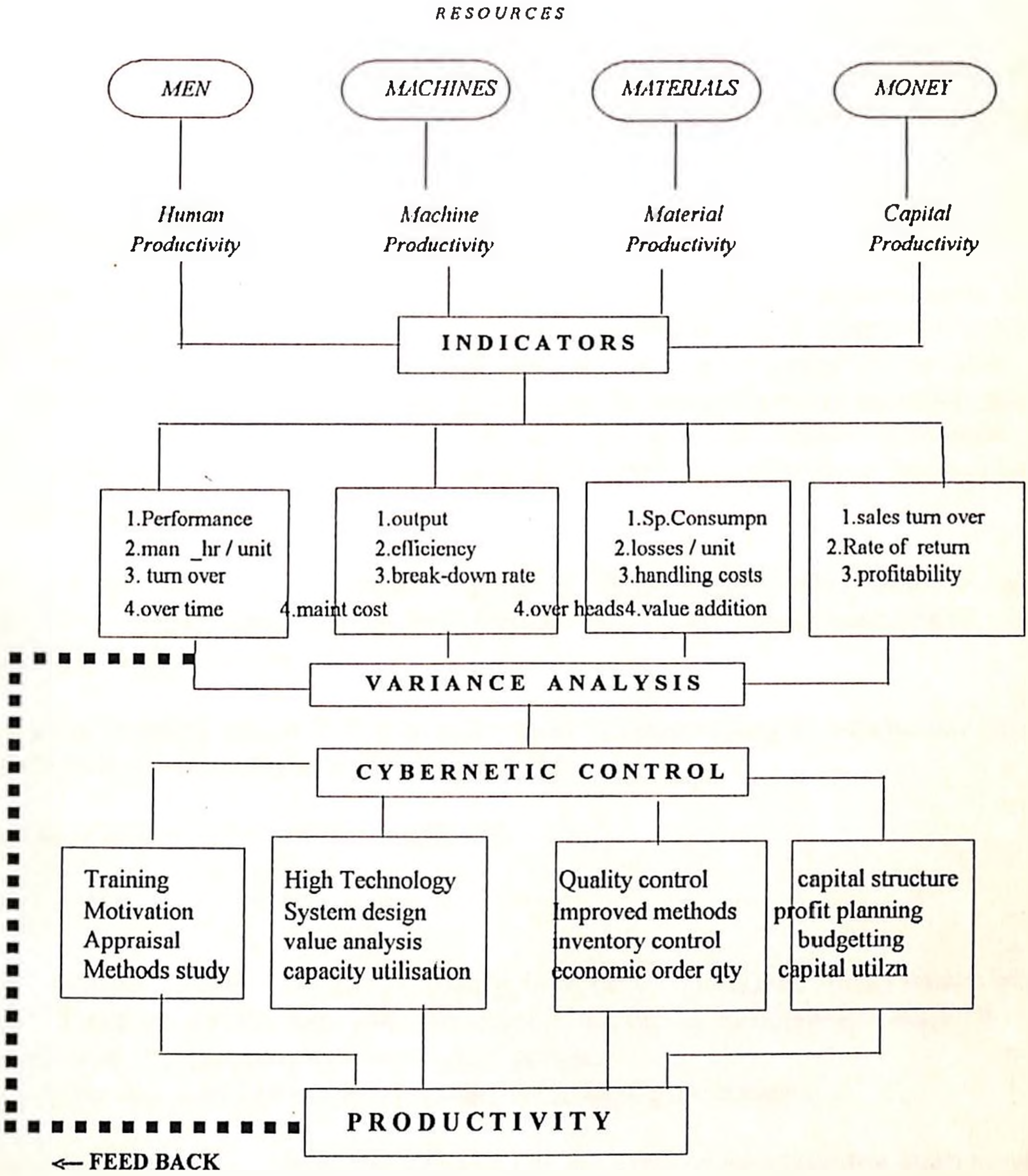
Conventional performance parameters:

Conventional performance parameters used for evaluating the process/ system performance are specific consumption values as given below (*2,3*).

a.Man_hour/unit production
b.Machine_hour / unit of production
c.Material Consumed/ unit of production.
d.cost of operation / maintenance /production etc /unit of production.

When these specific consumption parameters are minimum for all the sub systems or units, it shows efficient performance of the industry . When actual cost is assigned to each resource, the total cost will be minimum and profit / unit maximum when these objectives are fulfilled.

fig 2.01. Information Flow Diagram - Productivity Analysis and Monitoring.



(Ref 34)

Above concept may be applied to any industry irrespective of whether it is a chemical industry ,power industry or services organisation. It may be noted , this type of monitoring refers only to a particular type of resources mix which is ever dynamic and the performance vary with the technology , labor efficiency , knowledge base , experience level ,expertise gained etc. For efficient monitoring of these indicators, an elaborate data base of information pertaining to the system is necessary. This could be off-line or on-line depending on the type and modernisation level of the enterprise under consideration.

Impact of Resource mix on productivity:

Resource mix is one of the key parameters that controls the performance and productivity of any enterprise. There is no meaning in comparing the highly automated unit with that of a manually operated unit and say the performance of the later is inferior. Similarly, advanced technology will always be found superior to older ones with respect to production cost , performance and profitability . Hence performance monitoring by comparison must focus attention on identical type of units or technologically similar units .

There are also occasions in which 'high technology units' could not show any superiority over earlier technologies due to plant cost , learning level ,adaptability to the technology , know-how etc.

A linear programming model could be developed for optimising the resources mix. Directionally this may be expressed as given below.

$$\text{minimise } z = m1*C1 + m2*C2 + m3*C3$$

$$\begin{aligned} \text{ST} \quad & m1 <= x1 \\ & m2 <= x3 \\ & m3 <= x4 \end{aligned}$$

where m1,m2 & m3 are no of men,machines & materials respectively and C1,C2,C3 are specific investment equivalent in monetory terms such as Rs,US$ etc for producing the same product and same quantity.

x1,x2,x3 are the standard targets selected from best performers.

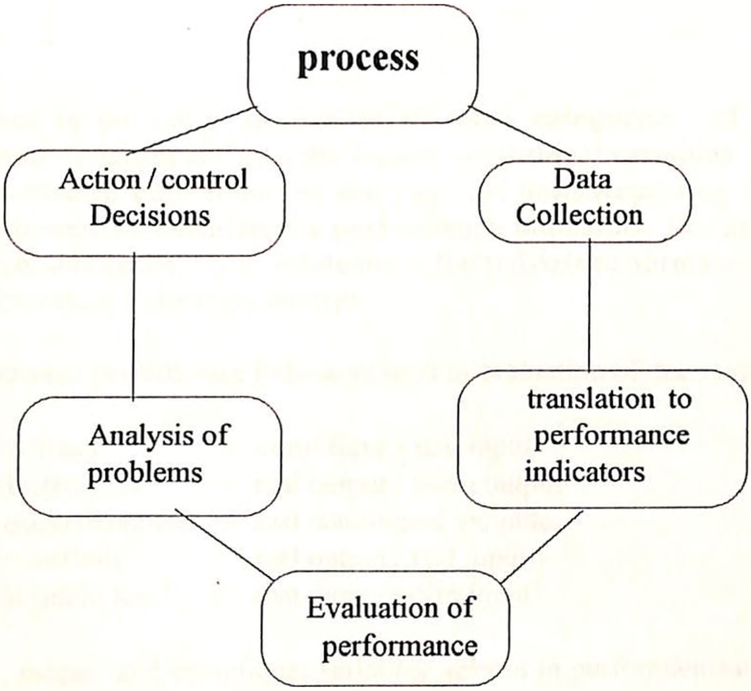
This clearly indicates , high efficiency machines are capable of replacing man power by substitution and high quality feed stocks also tend to improve productivity and output . While the impact of all these resources will have to be converted into a model form for clear understanding , *the unit under study will be assumed to have a particular resource mix* and the objective is to design a performance monitoring methodology to take certain managerial decisions. For monitoring the performance of invidual unit , parameters as given the **format 2.01** may be found useful and specific consumption targets may also be fixed based on the data .

This methodology , when applied on universal data, could spell out the optimal resources mix that minimises the total cost of production and offers the maximum productivity fulfilling all the constraints. Adequate caution must be exercised in this approach as the cost of materials, labor and machines also vary from state to state and country to country depending on the economic conditions , population growth rate, trained man-power availability etc. However, this may be valid for the same location , where the above factors are essentially constant.

The Control Cycle:

Management process essentially comprises of planning , execution and control of goal directed activities.Control processes are represented in the form of a control cycle as shown in *fig 2.02.* below. *(2)*

Fig 2.02 Activities in a Control Cycle.



Various stages of control cycle related to a process are given above.Performance Indicators in respect of any process comprises of the following steps.

1.Defining the objective
2.Defining the control strategy.
3.Making use of knowledge and experience for problem analysis.

4.Fixing norms and control boundaries.
5.Defining performance indicators.
6.Determining measurement methods.

Performance Indicators - General Transformation Model.

A general transformation model is the simplest way to understand what is meant by performance indicators . **Fig 2.03** given below represents a typical transformation model. This embraces activities concerned with transformation of input into output. This could include production processes , decision processes, development processes, control processes etc. Data related to the conditions of the transformation process are called 'conditional variables'.

Fig 2.03. The Transformation Model

Measurement is normally applicable to three categories of process data : inputs,conditional variables and outputs.Inputs, conditional variables and outputs can almost be expressed in both financial and physical units.Reporting the process data alone is not sufficient to calculate the performance indicators. For gaining an insight into performance, it is necessary to relate the collected data to norms or other data. Only after this, performance indicators emerge.

The most common performance indicators used in evaluation of the system are

1.Efficiency = norm input / real input
2.Effectiveness = real output / norm output
3.Process parameter = real conditional variable.
4.Productivity = real output / real input
5.Utilisation level = real input / norm input

A typical input , output and conditional variables related to performance indicators is given below.

Inputs(I)	*Conditional Variables(T)*	*outputs(O)*
Material	Throughput ,time	Production
Costs	Throughput,time	Sales
Personnel	Turnover speed	Deliveries
Capacity	Rejects	Turn over

Efficiency concerns the efforts , costs and reception of inputs when employed in the process in relation to the norms. Effectiveness concerns the amount to which the process realises the previously stated norms. **Format no 2.01** given in the next page is the basic input for evaluation of various performance parameters that could be used to determine the unit performance on a micro scale (32).

When this exercise is carried out for each section of the total system , and the performance is found satisfactory, the total system performance shall also be high . It is also possible to identify areas of improvement more precisely by this approach and performance evaluation of individual industry is possible for similar units operating under similar conditions.

All these information could be easily represented in a master data base (say **master.dbf**) which contains all the fields cotaining observed data and additional fields to evaluate the required performance parameter by suitable programs.The user will enter the data in their respective cells, which may be in a format form or regular data base form.

Informations that could be made available from such a system are

* what is the current feed mix & what is the cost ?
* what is the product pattern
* what is the profit at current level of operation ?
* what is the current loss and how much it should be ?
* which section incurs more loss etc.

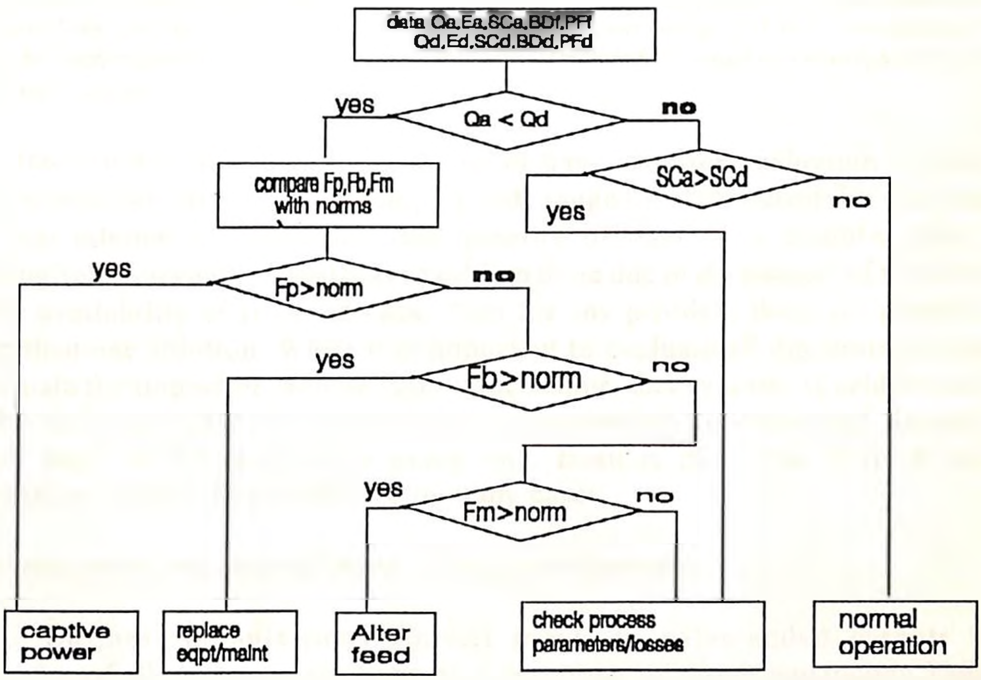
FORMAT 2.01. UNITWISE INFORMATION FOR O & M DECISIONS

Name of Unit:			Month/Week/Day:		
No	**Item**	**unit**	**target**	**actual**	**Variance**
1.	*Input:*				
	Feed A	tons			
	Feed B	tons			
	Feed C	tons			
2.	*Output:*				
	Product 1	tons			
	Product 2	tons			
	Product 3	tons			
3.	*Losses:*	tons			
4.	*Consumption:*				
	Power	kwh			
	Fuel	tons			
	Steam	tons			
	Chemicals	tons			
	Man_power	hrs			
	OT_Hrs	hrs			
	Maintenance	hrs			
	Spares	Rs			
5.	*Costs:*				
	Power	Rs/kwh			
	Fuel	Rs/ton			
	Steam	Rs/ton			
	Chemicals	Rs/ton			
	Man_power	Rs/hr			
	OT_hrs	Rs/hr			
	Maintenance	Rs/hr			
	Spares	Rs			
6.	*Total Cost:*	Rs			
7.	*Production Cost / unit*	Rs			

Name of Unit:			Month/Week/Day:		
No	Item	unit	target	actual	Variance
8	*Sales:*				
	Product 1 tons				
	Product 2 tons				
	Product 3 tons				
9.	*Inventory:*				
	Product 1 tons				
	Product 2 tons				
	Product 3 tons				
10.	*Costs:*				
	Feed A	Rs/t			
	Feed B	Rs/t			
	Feed C	Rs/t			
	Product 1 Rs/t				
	Product 2 Rs/t				
	Product 3 Rs/t				
11.	*Running Hrs Data*				
	On stream Hrs	Hrs			
	Break Down	Hrs			
	M/E/I/M	Hrs			
	Prodn Loss	tons			

Similar format may be used for all the units on a monthly / weekly/ daily basis to arrive at performance norms for taking appropriate decisions . Above information could be entered into a data base file using Dbase or Foxbase or Foxpro etc and could be selectively used for report generation. While the above information forms a mere data base, it is only the processing of the required data that could give meaningful information for taking O & M decisions at the right time and right cost. The success of computer aided management depends on the evaluation of performance parameters and identifying the parameters for deviations. Fig 2.04 represents a *typical Decision Flow diagram for plant performance analysis based on the above data .*

Fig 2.04 .Decision Flow Diagram for Plant Performance Analysis



Qa,Qd Actual and Design feed rates in tph,tpm,tpy
Sca,SCd Specific consumption figure in t/unit product
Fp,Fb,Fm Failure frequency of power,equipment,material. (*ref 13,34*)

In this model , effect of feed quality,technology and man-power availability are not considered.

Information flow for Executive Decisions:

Making effective decisions within any business is difficult even under favourable circumstances.The problem is all the more complex when the business becomes competitive or the available resources are very limited and the constraints are multifarious. In spite of all the bottlenecks ,it is the effective decision that ultimately leads to the business success of any organisation.

Many decision models designed to simplify decision making process have miserably failed to do so. Partly this is because of inflated expectations that managers had of these models. In many cases the damage had been done because the models were developed by someone who had no idea of the context or environment in which it will be used.Due to this,these models turned out to be inappropriate, unrealistic, inflexible and demanded too much of data inputs besides being too complex.

Effective decision making on the other hand requires evaluation of fairly large amount of data and processing of wide range of information for choosing the best alternative. Managing this quantity of data is so complex, that a thorough analysis and evaluation are seldom done due to the paucity of time and/ or the availability of required data. Also for any problem there are generally more than one solution. While it is important to evaluate all the strategies and anticipate the impact of each on future operations, this exercise is seldom done as this is a very difficult task involving complicated iterations and forecasts which may not be familiar to every one. Besides this, the cost of such evaluations tend to be prohibitive in many cases.

Information flow for Planning and Control - Primary role of managers

Business organisations convert inputs to value-added outputs by utilisation of all resources involving men ,machine , materials and money.These resources are required to be brought together to achieve their conversion successfully.The creation of an organisation or enterprise is imperative to do this.But the maintenance of the viability of an organisation requires that the relevant operations are planned and controlled.This is the basic function of management in any organisation.

For achieving this certain vital information are required by managers. The success of any organisation may be taken as proportional to the effectiveness in planning and control mechanism and the quality of decisions and the appropriate time at which decisions are taken .' Indecision is a silent killer of the organisation ' .

Information flow for Executive Decisions:

Making effective decisions within any business is difficult even under favourable circumstances.The problem is all the more complex when the business becomes competitive or the available resources are very limited and the constraints are multifarious. In spite of all the bottlenecks ,it is the effective decision that ultimately leads to the business success of any organisation.

Many decision models designed to simplify decision making process have miserably failed to do so. Partly this is because of inflated expectations that managers had of these models. In many cases the damage had been done because the models were developed by someone who had no idea of the context or environment in which it will be used.Due to this,these models turned out to be inappropriate, unrealistic, inflexible and demanded too much of data inputs besides being too complex.

Effective decision making on the other hand requires evaluation of fairly large amount of data and processing of wide range of information for choosing the best alternative. Managing this quantity of data is so complex, that a thorough analysis and evaluation are seldom done due to the paucity of time and/ or the availability of required data. Also for any problem there are generally more than one solution. While it is important to evaluate all the strategies and anticipate the impact of each on future operations, this exercise is seldom done as this is a very difficult task involving complicated iterations and forecasts which may not be familiar to every one. Besides this, the cost of such evaluations tend to be prohibitive in many cases.

Information flow for Planning and Control - Primary role of managers

Business organisations convert inputs to value-added outputs by utilisation of all resources involving men ,machine , materials and money.These resources are required to be brought together to achieve their conversion successfully.The creation of an organisation or enterprise is imperative to do this.But the maintenance of the viability of an organisation requires that the relevant operations are planned and controlled.This is the basic function of management in any organisation.

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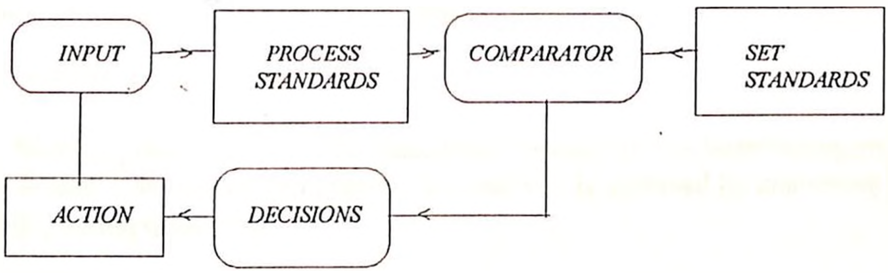
Models for planning and control.

Many don't realise that models play an important role in planning and monitoring . It is not possible for a manager to monitor an operation sensibly ,if he has no idea of how the operation functions and what role each parameter plays on the objectives sought . In a state of complete ignorance, a manager will have no idea of what things to look for to identify actual or potential problems.This has been observed in most of the problematic organisations and a muddle of confusion exists every where. A typical planning and control mechanism may be represented as shown in fig **2.05.**

FIG 2.05. PLANNING AND CONTROL MECHANISM.



To be competent,a manager must have a model against which he can assess the behaviour of operations for which he is responsible and also allows him to asses the impact of actions he plans to take. **Fig 2.05** given above represents this concept of planning and control of any operation.

Input requirements for any operation / business is determined by comparing the actual performance / standard with planned / standard performance . By variance analysis, decisions are taken to minimise this variation and relevant actions are taken to change the input parameters consistent with the deviation.This control is called Cybernetic Control.

Computers for planning and control.

Undoubtedly computers can be used effectively to improve not only the decision making process but also the quality of decisions as these electronic devices can perform and process tedious iterations and calculations more easily and effectively within an unbelievably short time. Evaluation of alternatives and sensitivity analysis can be simplified for taking proper decisions from a network of decisions.

This thesis covers computer applications pertaining to

* Operations/Production Management
* Financial Management
* Marketing Management
* Materials Management
* Personnel Management
* Statistical application tools and quantitative methods.
* Managerial Economic problems (micro economics)

Examples given pertain to above managerial areas and the computer outputs given are based on Lotus 123 / Advanced Basica/ Qbasic/ Dbase III / Foxpro2 or other executable programs that could be easily developed by knowing the sequence of decisions and decision flow .

Information Design:

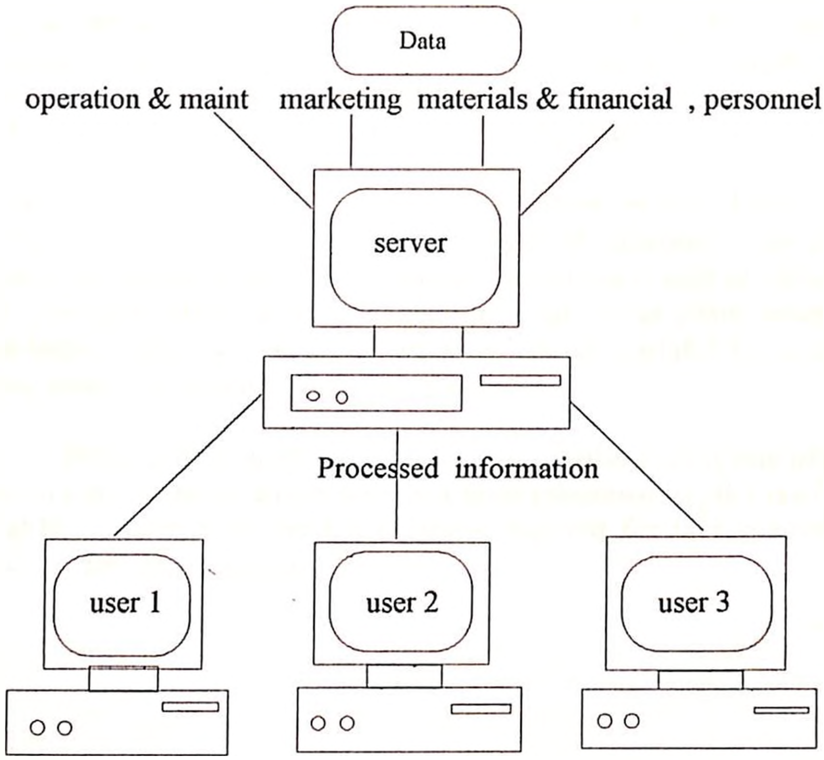
Most important activity, that determines successful data base management and processing is the information design. The activity is analysed by answering the following probing questions.

* Who is the user of this information ?
* What are the informations required for him ?
* How well could this info be used for decision-making in his level ?
* What is the hierarchial importance of this info ?*(critical ,desirable ,normal)*
* What impact will it make if the info failure take place ?
* Whether he needs the processed info or only the data etc.

Above guide lines may be used for designing the size of information data base , hardware / software configurations , networking etc of the total organsation.

When raw data is used from the server *(main station)* , each section could retrieve the data required by him, process the info and convert into desired decision outputs. Alternately, the server station itself can convert the relevant data into required output and transfer the decision output to the individual users. A typical system is shown in fig 2.06. Here again the data input to the main station could be manual or from a DIDC system or a combination of the two depending on the degree of automation required. Degree of automation enhances the cost of information and hence there exists a need to carry out an economic balance for each system / sub system .

fig 2.06. Design of information system for Decision making



Conventional Information need of individual sections are given in the **Format 2.01.**

Since the information needs are system specific, no general data base can be given.However, for a process industry following information needs are considered to be sufficient by various departments / departmental executives.

a.Operations and Maintenance Section: Throughput of each unit, products, specific consumption of energy,utilities,chemicals,product quality, operating costs break-up, delays in commissioning, shut-down hrs,production losses,equipment failure, maintenance hours, cost of maintenance, failure frequency etc.

b.Marketing division: Product sales, zone wise, area wise, product wise. Inventory level of products, cash sales, credit sales , consumer complaints, action taken, product positioning, market analysis , competitors product sales, impact of substitutes, product pricing etc.

c.Materials Division: Inventory of raw materials, products,consummables, stock-outs, lead times,deliveries, receipts, quality, cost, loss on storage,pilferage losses, vendor development etc.

d. Human Resources Development Section: No of manned position, qualification and experience, age profile, retirement info, recruiment evaluation, training evaluation , wage and salary info, turn-over rate, absenteism, discipline maintenance, perks, over-time info, human-resourcs analysis etc.

f.Financial Information: This is the most important section of the organisation and controls the profit centre effectively. Required information for this section are, production rates, product rates, cost of production, cost of utilities, chemicals and consummables, capacity utilisation, man-power costs, maintenance costs, cash inflow, outflow, bad debts, working capital availability, inventory carrying costs, payment schedule / administration etc.

Since overall management success involves synthesis of the individual section performance, which have got inter relationship , the **chief executive** must be able to access all the information required for taking suitable corporate decision for implementation.

MODELLING TECHNIQUES FOR DECISION-MAKING

Chapter 3. Modelling Techniques for Decision Making

This thesis is about creating and using models for developing a computer decision support system (DSS) . A decision model is any quantitative or logical abstraction of reality that is created to take a decision in the right direction without losing track of the constraints and goals .It consists of quantities and relationships . A DSS is the conduit for creating, revising, checking , and reviewing the decisions and their impact using the model . In it's crudest form, the DSS may consist of a spread sheet planning system such as Visicalc or an equation solver.

Models are used for decision making and they help to respond to much more complexity than one person can grasp and resolve. Secondly, models can keep track of many details and perform all computations rapidly *.This allows the modeler to devote attention to judgements made about the individual details and composite results produced by the model .Models are very useful in complex situations, where simpler approaches don't suffice.* **Models are not part of a goal - the decision is the goal.** *(4)*

Techniques of model development: The process of developing a quantitative model involves five steps as explained below.

1.Identifying the objectives of the decision maker and the associated performance measures or attributes , the decision variables , and all the other variables to be used in the model.
2.Structuring the influence relationships among the attributes and variables of the model.
3.Specifying the form of relationship for each influence.
4.Estimating the numbers that are to be used in the model.
5.Using the model to analyse the problem , including a sensitivity analysis and a risk analysis.

What managers need is to develop judgement about modelling. This requires first an understanding of the meaning of various forms of models. Secondly, the manager needs experience , which is obtained by trying out ideas on a few exercises and cases.

When once the variables are identified, (as in the case of two variables), it is possible to know from a glance whether or not variables are related and if so whether the relationship is linear or non-linear etc . For this purpose, even a spread sheet program like *lotus123* may be used.

Since the objective of model building in our case refers to *techno - managerial applications*, the models are also classified into scientific models and business application models.

Starting from the production function , following models are of immense use for process industries as given below.

Production:

1.Product demand model (time-dependent type)
2.Materials requirement planning model
3.Utilities requirement model
4.Feed mix model
5.Production planning model
6.Unit performance models
7.Yield prediction model
8.Operating cost model
9.Specific consumption model
10.Flexi targeting model etc.

Maintenance:

1.Equipment failure / break-down frequency models
2.Maintenance cost model
3.Residual life Assessment model
4.Equipment maintenance / replacement model
5.Optimal replacement time model
6.A,B,C classification of equipments for maintenance decisions
7.Reliability models
8.Equipment performance models.

Marketing:

1.Sales forecast productwise and regionwise
2.Market research models
3.Impact of advertisement effort on sales.
4.Selling price vs sales turn over.
5.Product positioning and market analysis models
6.Impact of product substitutes
7.SWOT analysis.
8.Marketing strategy applications.

Materials:

1.ABC classification of materials
2.Material Consumption models
3.Inventory Analysis

4.Optimal Inventory model
5.Stock-out Analysis
6.Vendor performance evaluation model
7.Material performance evaluation model
8.Substitute development

Financial:

1.Sales rate and cash-inflow forecasts
2.Profit maximisation model
3.Cost Analysis model
4.Cost centre identification
5.Cost minimisation strategy development
6.Improvement of capital productivity
7.Bad debts minimisation.

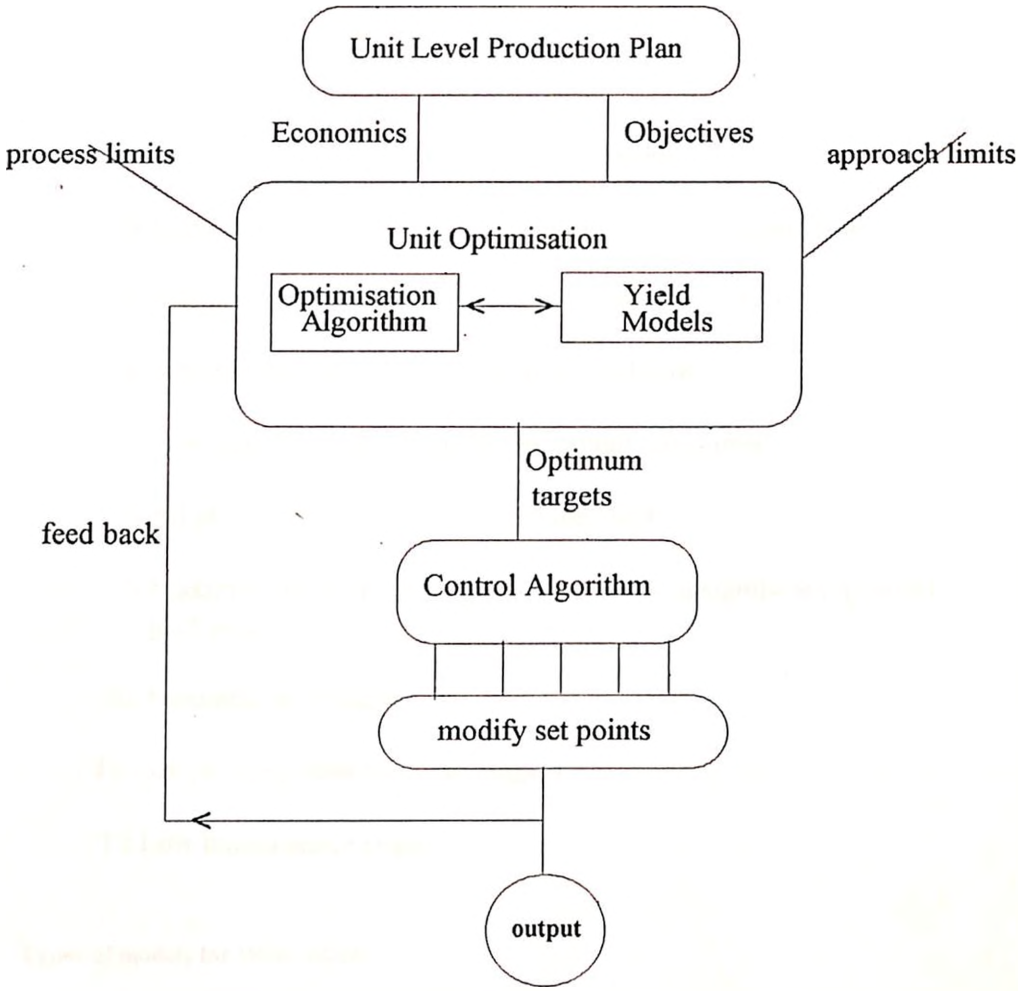
Human Resources :

1.Maintaining data base of employees
2.Identifying training needs
3.Recruitment rate determination
4.Human Resource evaluation
5.Identification of right person for the right job.
6.Wage administration
7.Over-time control
8.Evaluation of Job contracting
9.Discipline administration
10.Welfare activities
11.Motivation etc

In addition to the above, there are a number of 'technical programs ' such as process simulation, operations analysis etc that will be used in the industry. Information from these will be used for taking certain operational decisions.

Each operational activity is linked to the managerial objectives / operation guide lines. This is determined by market situation. Based on this operational objective, plant operating conditions will have to be optimised. Since this is a dynamic activity, and changes from time to time there is a need to change the operating conditions in response to these variations. This could be achieved only by a computer-aided manufacturing system which in process industry is called DIDC (Distributed Digital Control) and this is linked to the environment as shown in **fig 3.01.** *This concept could be applied to any complex industry without exception and the productivity of such a system is very high in view of the immediate response to the environmental conditions and demands .*

Fig 3.01 Optimiser interaction with operational objectives and Product Demand Scenario.



Operating conditions will be changed when the product pattern demand or feed quality changes for the system.This is a dynamic situation.Under these conditions, all the operating parameters of the system / sub systems will have to be necessarily changed to meet the target . This change has economic implications.Hence, an optimiser algorithm is used to optimise the feed mix and operating severity / conditions so that the targets are met at minimum cost. This automatically sets the operating parameters by a transducer interface where the digital signals are controlled to analog and vice-versa.

Advantages of DIDC system:

1.Meets stringent product quality specifications easily.

2.Stable operation of all units

3.Maximisation of high value-added products

4.Maximum energy recovery and low energy consumption

5.Maximum throughput (high machine productivity)

6.Smooth change over and minimum lead time.

7.Low process loss and better equipment utilisation.

8.All process and economic constraints met.

9.Maximum profit to the organisation due to insignificant product give away.

10.Amenable to changes.

11.Longer equipment life , run lengths

12.Low maintenance costs.

Types of models for DSS: *(16,36)*

A number of models are in use for decision making. Some of them are functional models as given below.

1.Linear: The most common general function is a straight line or linear function as given by

$$y = a + b * x$$

where x and y are variables and a & b are constants.

A typical example could be a forecasting model for the product. Product demand increases with time. Hence it is possible to determine the product demand at a future period using this model.

In operating situation other examples are total cost which may be represented by

*total cost = a + b * production volume.*

This means for every unit increase in production, total cost will increase by a fixed amount and even when there is no production, certain costs will have to be incurred.

2.Quadratic model: Some times, the increase in the dependent variable for unit increase in the independent variable changes for different levels of the independent variable. This could be of the form

$$y = a + b * x * x$$

A typical example is the market share of a product which is given by

*Market Share = a + b * Advt Share * Advt Share*

3.Power Curves: Some of the models have a power greater than two attached to the independent variable. This is of the form

$$y = a + b * x * x * x$$

A typical example is the space requirement in a process plant for erection of a column or vessel which is represented by

*Lay out space required = a + b * dia * dia * dia*

where dia is the diameter of vessel in metres and space required is in m3 and a & b are constants.

4.Fractional Power Curves: In certain cases, the exponent of x happens to be a fraction (i.e. less than 1) . This could be of the form

$$y = a + b * x^{0.5}$$

A typical example is the total cost vs production volume in some cases as given by

*total cost = a + b * Prodn Volume*$^{0.5}$

5.Exponential models : A very useful model, particularly for forecasting the growth rate of population , economic indices , energy consumption etc.

This is of the form

$$y = a * e^{b * x}$$

Typical examples are population growth , specific energy consumption etc and is given by

$$Population = a * e^{b * time}$$

6.Logarithmic models : In some cases, relationship between variables follw inverse of exponential relationship.

This is called logarithmic model which is of the form

$$y = a + b * ln(x)$$

A typical example is the modelling for competitive marketing situation where the user wants to determine the time to enter the market of a competitor's product. On the assumption that the competitor will enter only when the market is several times larger than now (called critical size) this may be given by

$$critical\ size = e^{0.2 * time\ to\ entry}$$

7.Logistic Model: The S shaped logistic function is a natural model of a variety of situations, particularly life-cycle growth.For example, the initial growth of sales of a new product may have an S shape.Start up growth is low , which then picks up to a fast growth rate then tails off as the market is saturated.

The general expression of such a model is given by

$$y = \frac{a}{1 + b * e^{\wedge}(- c * x)}$$

8.Multi variable linear models: In many cases, more than one independent variable may influence a dependent variable.Typical example is the utility demand for a total system comprising of many sub systems.

This is represented by

$$y = a + b * x1 + c * x3 + d * x4$$

where

y is the total utility demand to be met
x1,x2,x3 and x4 are unit throughput of unit 1, unit2 etc
a,b,c,d are constants.

This could be solved by multi variable regression model using **lotus 123**
Most of the operational models fall in this category.

9.Multivariable non-linear models: In some cases, variables are not linearly related but may be non linear in nature. Such a model is given by

$$y = a * (x1)^{b} * (x2)^{c} * (x3)^{d} * (x4)^{e}$$

This thesis covers a number of models developed using Lotus 123 or SCIMOD for developing the DSS system for taking crucial decisions. This will be described in each model.This will describe the identified variables, their relationship and model output along with 'what-if' or sensitivity analysis.

Model Validation:

When dependencies have been identified and a model is developed, a model is just born.But it is not yet fully developed. Though it is very tempting to go to the results directly from the model, the accuracy of the model must be tested lest it may be found faulty. A good method is to validate the integrity of the model , improve it or shrink it till it produces the reliable results.

What-if and sensitivity analysis :

In ' what-if ' analysis, the value of a variable is changed and the model is resolved . Sensitivity analysis is just an extended form of what-if analysis, where the level of a variable or variables is automatically incremented by a given amount over a specified range and the effect on a specified variable is determined. This may be effectively used to determine which variable affects the outcome attribute and find the path of great influence.

Extend and Refine the model :

Starting with a simple model such as a two variable model , if another influencing variable has to be added, it should have influence on the outcome next to what has been considered. Iteratively, the model is extended adding one variable or influence at a time.

Integrating Models into DSS sustem:

Since the main objective of a model is to offer a DSS *input to the decision maker, these models could be incorporated into the main module*. When once the relevent data is entered or accessed the program automatically gives the actual outcome to the desired outcome for comparison . This has been shown in some of the program outputs especially in Production Models output section.

By integrating these discrete models into the system such as LAN or WAN, it is possible to arrive at an overview of the entire system very easily .By suitable programming , decision maker may even get an abnormality report generated for necessary and immediate action. Modern concept of Expert System , Artificial Intelligence etc may also be incorporated to get useful outputs for decision making.

OSA MODELS
FOR
DECISION MAKING

Chapter 4. OPERATIONS SIMULATION ANALYSIS MODELS.

Introduction: Operation Simulation Analysis (OSA) helps commercial plants achieve maximum operating flexibility and make higher profits. Based on years of design , operation and advanced control experience in process optimisation , it has been found that operation simulation analysis is the best approach to achieve optimal design and profitable operation. (*Ref 7,6*)

In competitive marketing scenario , the gap between supply and demand tends to enhance the feed stock and energy costs which has forced the chemical industries to seek operating flexibility for achieving high profits.The tangible benefits achievable by OSA models are

* Energy conservation of at least 10%
* Maximised product recovery
* Operating flexibility to process different and diverse feed stocks
* To meet product specifications at the lowest operating cost.
* Maximise plant / equipment performance through debottlenecking etc.

Most of the operating plants which have been designed earlier, are not able to achieve these goals due to

* lower energy cost design basis.
* design for fixed feed stocks and operating conditions without provision for corrections for new conditions.
* wasting excessive energy for meeting the product specification. (e.g. over fractionation in distillation)
* bottlenecks in equipment sizing, conditions etc for new feed stock processing.
* less accurate design methods (such as chemical kinetics, vapour liquid equilibrium etc resulting in lower reactor yields, overhead products etc)
* over design in capacity (10 to 25%)

The discrepancy between the design and operation created by energy crisis has created a demand for a new technology / method for improved design and operation policy. In competitive situations, the stress is more for higher operating efficiency of equipments. *Without an operations simulation model, optimisation of the system is quite impossible and this method could be applied to any plant operation.Even the advanced computer control and optimisation of a commercial plant cannot achieve optimal operation due to*

* Reliability of computer and instrument hardware and data logging system
* Reliability of the process model and control model.Usually, these models fail to control the full range variation of the operating conditions due to poor project planning and lack of understanding of the response relation among the operating variables.

  This problem has resulted in by-passing of the control system in many plants who claim to have installed a DIDC system and advanced controls.

* The gap between engineering design, commmpercial operation and computer hardware and software continues to be too wide due to operations feed back.

OSA Technique:

1.Design Review: Most up-dated reliable chemical engineering principles to re-design the existing plant and identify the discrepancy between design and opera tion.

2.Improve the design: Energy conservation through waste heat recovery, reduced product loss and modified design if necessary.

3.Data collection and instrument calibration : Collection and screening of 6 months to a full year of operating data log sheets is required to cover the full range of variations due to feed stock and seasonal variation impact on the operating conditions.

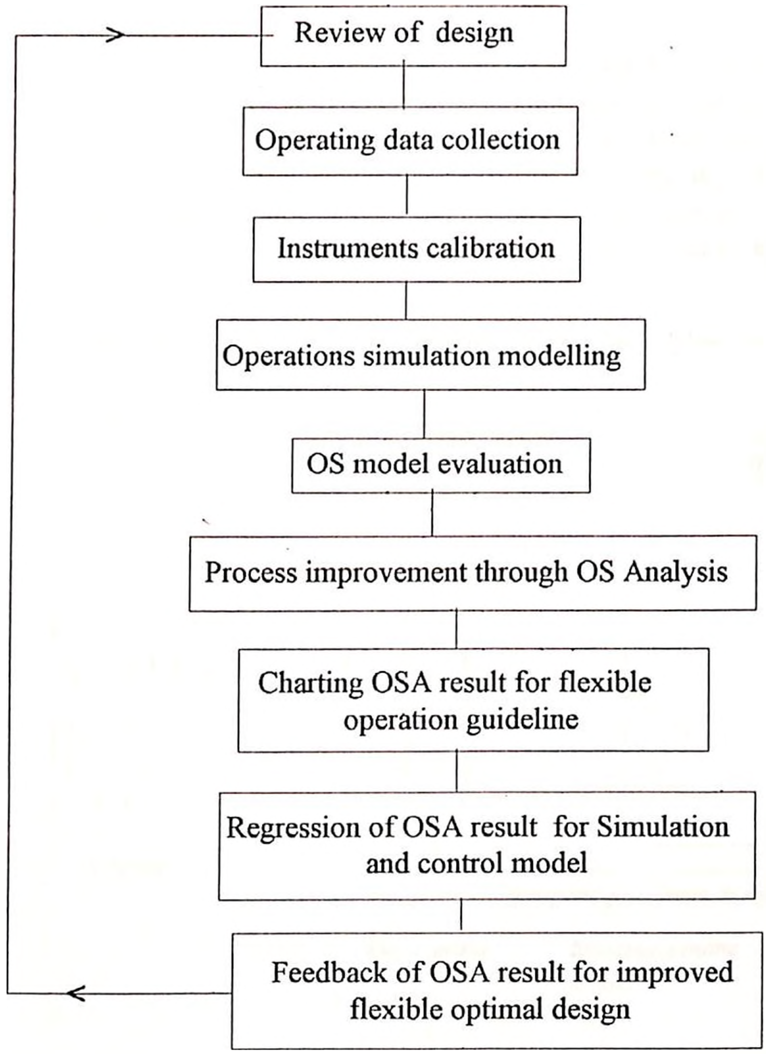
4.Building of operations simulation models: Start either from design simulation model or statistical regression model to reflect the response surface of various operating variables (cover full range variation).

Evaluate the OS model against full years operating data to arrive at reliable OS model. Use the OS model to provide Operations Simulation Analysis (OSA) for the comm -ercial plant to achieve optimal operation.(maximum recovery at minimum energy)

The OSA result is to provide operators flexible operating guide lines to achieve flexible operations at all times.Regression of OSA results to provide a reliable computer / micro processor control model . Feed back of the OSA results to the design to achieve flexible optimal design.

A decision flow diagram is given in *fig 4.01* to indicate the steps involved in OSA technique .

Fig 4.01 . Steps involved in Operations Simulation Analysis.

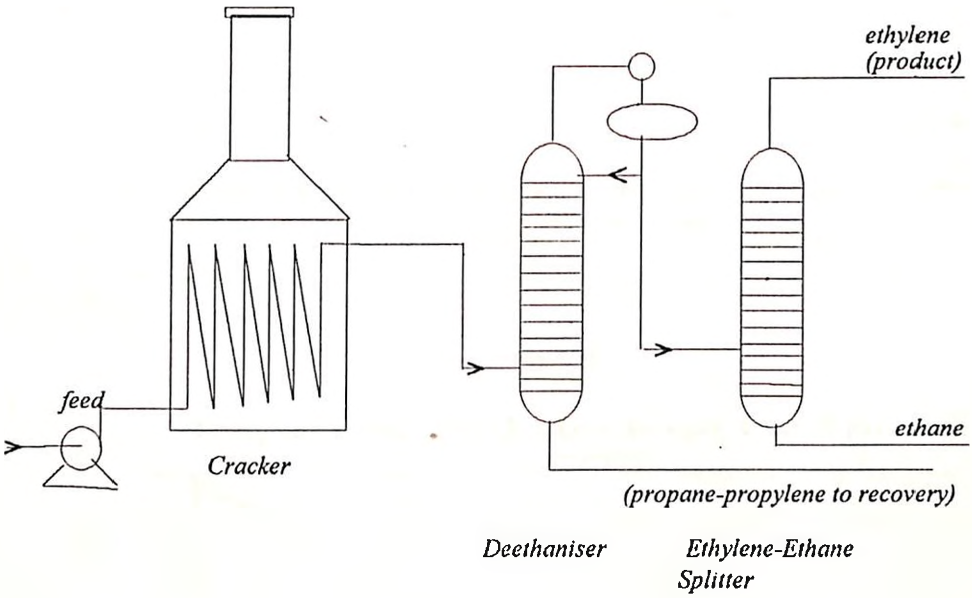


A typical program output is given with reference to a commercial naphtha cracker using the actual operating data and the above steps for developing the model. *(6,7)* . This activity , related to DIDC is called *'Scoping Studies '*

Operations Simulation Analysis- Example : *(Ref 6,7)*

An example related to a naphtha cracker is given here (fig 4.02). This unit was originally operating as a light naphtha cracker, but now the unit operates to crack feed stocks ranging from lighter C5 feeds to Kerosene. With feed stocks variation, deethaniser and C2 splitter feed stock composition also vary as given in figs 4.03 & 4.04 . If the original design conditions are maintained by the operator , excessive loss of propylene in the deethaniser and ethylene in the C2 splitter will be experienced.

Fig 4.02 Flow diagram of a cracker in operation for Ethylene production



Note: When the feed quality to the cracker is different from the design feed stock, feed quality to Deethaniser varies. This in turn affects C2 splitter feed quality i.e. C2H4/C2H6 ratio. For achieving the required purity level, reflux ratios will have to be modified.This in turn will affect the yield of ethylene . Hence OSA models may be used to solve this problem. The linear model developed using Lotus 123 , Data Regression command.*(37,39)* is given in *table 4.01 and 4.02.*

It may be noted that if the operating parameters are strictly maintained as per design, the unit would have incurred severe loss of production of ethylene as well as propylene which are high value products.

Fig 4.03

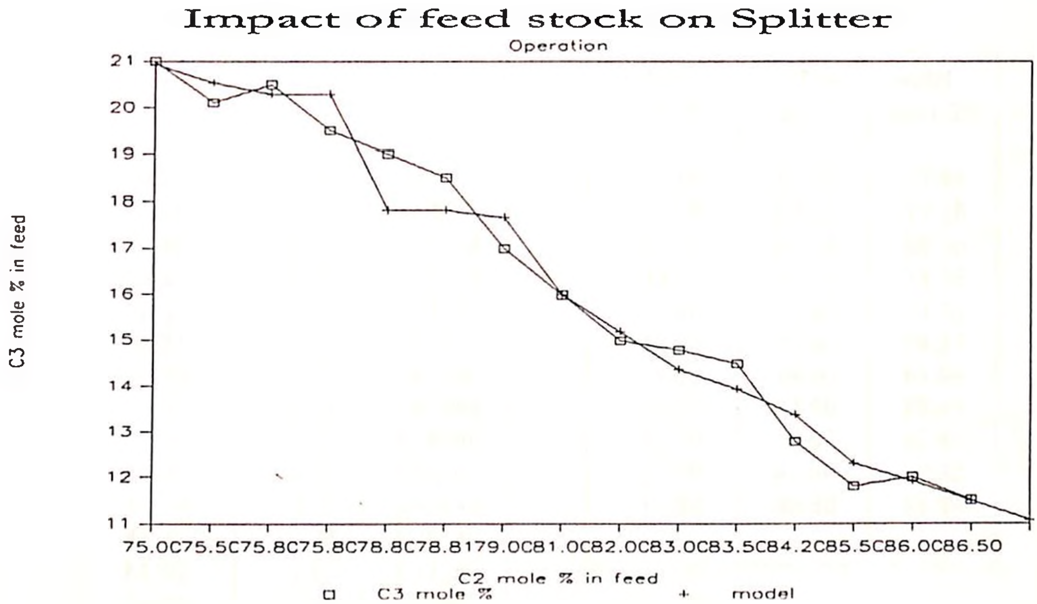


Fig 4.04

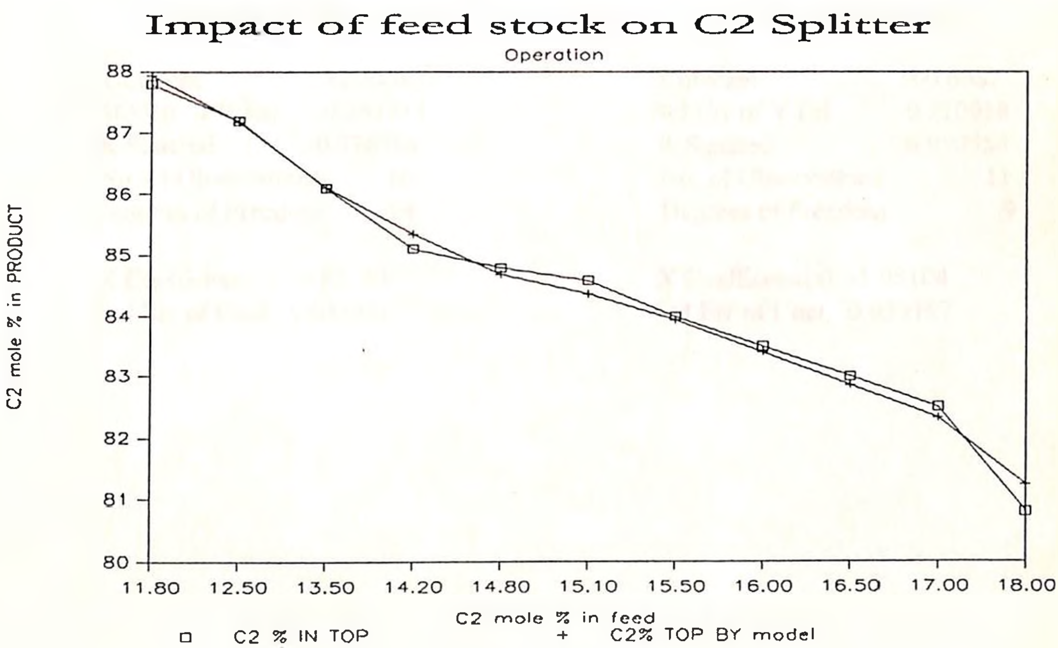


Table 4.01

Deethaniser feed composition variations
Data based on daily log sheets.

C2's	C3's	model
75.00	21.00	20.93831
75.50	20.10	20.52761
75.80	20.50	20.28118
75.80	19.50	20.28118
78.80	19.00	17.81697
78.81	18.50	17.80876
79.00	17.00	17.65269
81.00	16.00	16.00988
82.00	15.00	15.18848
83.00	14.80	14.36707
83.50	14.50	13.95637
84.20	12.80	13.3814
85.50	11.80	12.3136
86.00	12.00	11.9029
86.50	11.50	11.4922
87.00	11.00	11.0814

Regression Output:

Constant	82.54365
Std Err of Y Est	0.553213
R Squared	0.976754
No. of Observations	16
Degrees of Freedom	14
X Coefficient(s)	-0.82140
Std Err of Coef.	0.033866

C2 Splitter Operation Analysis
from log data

C2 % feed	C2 % top	model top C2%
11.80	87.80	87.94
12.50	87.20	87.18
13.50	86.10	86.10
14.20	85.10	85.35
14.80	84.80	84.70
15.10	84.60	84.37
15.50	84.00	83.94
16.00	83.50	83.40
16.50	83.00	82.86
17.00	82.50	82.32
18.00	80.80	81.24

Regression Output:

Constant	100.6967
Std Err of Y Est	0.210918
R Squared	0.990554
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	-1.08104
Std Err of Coef.	0.035187

Table 4.02

Impact of Reflux Ratio on Product Purity of Splitter

C2H4/C2H6 RATIO	R/F RATIO	PRODUCT PURITY%	BY MODEL
4.000	3.230	99.940	99.940
5.000	3.230	99.930	99.932
6.000	3.230	99.920	99.924
7.000	3.230	99.910	99.916
4.000	3.150	99.890	99.886
5.000	3.150	99.885	99.878
6.000	3.150	99.880	99.870
7.000	3.150	99.878	99.862
4.000	3.100	99.850	99.853
5.000	3.100	99.840	99.845
6.000	3.100	99.830	99.836
7.000	3.100	99.820	99.828

Regression Output:

Constant	97.78767
Std Err of Y Est	0.008204
R Squared	0.965011
No. of Observations	12
Degrees of Freedom	9

X Coefficient(s)	-0.00803	0.676453
Std Err of Coef.	0.002118	0.044235

Conclusion:

Above example is shown only to indicate how **OSA** technique may be used effectively to improve the operation of the plant, by analytical method which otherwise is highly complicated and confusing . This has been extensively used in a number of process retrofits and revamps successfully . For on-going units , these models may be used to give a **decision support** to modify / amend the operating parameters for achieving the desired objective *(6,7, 10,11,19) which is also the basic theme of the thesis .*

EORT MODELS
AND
PROCESS DECISIONS

Evolutionary Operations Research Technique (EORT in short) involves very systematic small changes in process variables during the operation of the process. The results of previous small changes may be used to suggest further changes so as to approach the optimum operating conditions by a series of small steps. Care is taken to ensure that these individual changes in these parameters do not upset the process nor produce any undesirable outcomes.

Evolutionary Operations Research technique *(4,10,18)* may be used to identify the combination of multi variables, to enhance the response surface of any operation which in turn improves the operational objectives and also the productivity of the complex system considerably.

The basic concept underlying EORT is that a smooth response surface exists for a set of variables, which ultimately tend to converge to a single optimum. This is the principle of Advanced Control System where the impact of minor variations of process parameters are used to vary other parameters to maximise or minimise the objective function. *(e.g. maximise the distillates, LPG, & minimise FO, coke make, maximise conversion, minimise operation cost, energy consumption maximise fertilizer (urea, ammonia) output for the same inputs etc.)*

Benefits of EORT models:

*EORT models are based on actual process variables which are dynamic in nature and fluctuate due to exogenous or endogenous factors. Since the effect of these manipulable variables form the inputs to the models, the outcomes should naturally be far more precise and accurate.

*EORT models may be used for carrying out the most needed sensitivity analysis of the dynamic system to identify the output trend for a set of new variables and / or operating conditions.

*EORT models may also be used to determine and monitor the system efficiency as a whole and also the sub system constituting them. Hence corrective actions may be taken more precisely.

*EORT models are real life operating models and combines the expertise of the operations group & the system's behavior to arrive at right decision compatible with the system.

*EORT models are deterministic in nature as the variables and their inter- relationships are evaluated by observed values and performance rather than theoretical / design mode models.

*EORT models are system specific and cannot be generalised to all similar situations.

For developing a generalised model all variables constituting the total macro system will have to be considered as data inputs for developing the macro level model. A generalised model suffers from the setback of lower accuracy. *Yet, it may be used for investigating the directional changes in the output for various dynamic changes of input parameters encountered in actual process operation.* Certain live examples related to a complex fertilizer industry is given in this thesis .

EORT Modeling programs are designed for generation of a set of *Decision Models based on LP/NLP algorithms* and serve as a very powerful, effective and result oriented *Decision Support System (DSS in short).*These quantitative Decision Models are logical abstraction of reality under which the total complex system operates. While simulation models are based on certain assumptions and hypothesis, which in practise may not be very true or valid, EORT models are based on observed facts and figures. All constraints experienced in actual practise and /or operation are reflected in the model.

This DSS serves as a conduit for creating, revising, reviewing and checking the real performance of the total system or subsystems which are constituents of the main system. Also it is possible to achieve the operational objectives more easily than one can visualise.

Typical Applications:

This technique may be used in the fertilizer industry, in the following specific areas of operations Management.*(36)*

* Monitoring performance of catalytic reactors such as Shift Converters,Ammonia Converters, Urea Converters etc.
* Impact of manipulable process parameters on conversion, yield etc.
* Catalyst condition monitoring
* Estimation of Optimum Catalyst Replacement time
* Cooler/Condenser performance prediction & fouling rate determination for taking tube bundle cleaning / replacement decisions.

* Cooling water quality monitoring
* Evaluation of inhibitor performance
* Equipment deterioration study etc.

Based on the above principles, a number of models for the Shift Converter of one of the Indian fertilizer units have been developed , the details of which are given in the enclosed figures.

Methodology of EORT Modelling *(35)*

Following steps are to be followed meticulously to develop a very reliable and valid Model for the process industry.

1. Defining the objective of the model
2. Outlining the general process and data collection
3. Identifying the manipulable and non manipulable variables either by observed data, analytical data or a combination of both
4. Developing basic Model with the identified variables which affect the objective function,and deleting the least effective variables by model revalidation.
5. Sensitivity analysis and model validation by manipulating the variables and comparing the observed output with model output.
6. Checking model validity under observed conditions for a stipulated range of variables.
7. No validation will be deemed necessary if the deviation between observed and model outputs are within the specified statistical limits.

When once last stage has been reached, the model will be accepted as valid and will form a basic DSS tool, by which the actual performance of the system may be evaluated and compared & the reason for any discrepancy may be identified for remedial action.

If the variation is explainable, the decision maker may correct the situation immediately.On the other hand, if the variation is not explainable or much higher than the stipulated statistical limits, the situation may be taken as out of control and warrants thorough investigation by way of process analysis, test runs, inspection etc.

Hence **EORT** models are capable of giving the warning signals at **Right Time** and could easily avert inefficiency or even disaster in some cases.

Enclosed herewith are some computer outputs of the models related to Shift Conversion Process of a Fertilizer Plant.The model has been used to determine *(18,36)*

1. Conversion efficiency of HT & LT converter with the passage of time
2. Catalyst Aging with reaction severity & stream days
3. Effect of process parameters such as Steam/CO ratio, feed rate, Concentration of CO, Reaction temperature etc on conversion
4. A simple Conversion efficiency Model as a function of time only.

It may be seen from the outputs and the figures enclosed, how useful these models are for *operational analysis and trouble shooting and how they may be effectively utilised for improving the productivity of the process by enhanced cycle lengths, catalyst activity, conversion efficiency etc.* This may be also utilised for optimising the ever **dynamic process** parameters. Using the same technique, process models may be developed for Ammonia Conversion, Hydro Desulphurisation, Catalytic Reforming, Delayed Coking, Aromatic Extraction etc.

EORT Application for Fertilizer Unit :

Following example refers to a *Partial Oxidation Route Fertilizer industry* situated in India. The process comprises of a Gasifier,Carbon scrubber, Desulphuriser, Shift converter, Decarbonator , Ammonia Synthesis, Air Separation Unit, Nitrogen Wash Unit and Urea Conversion Unit.

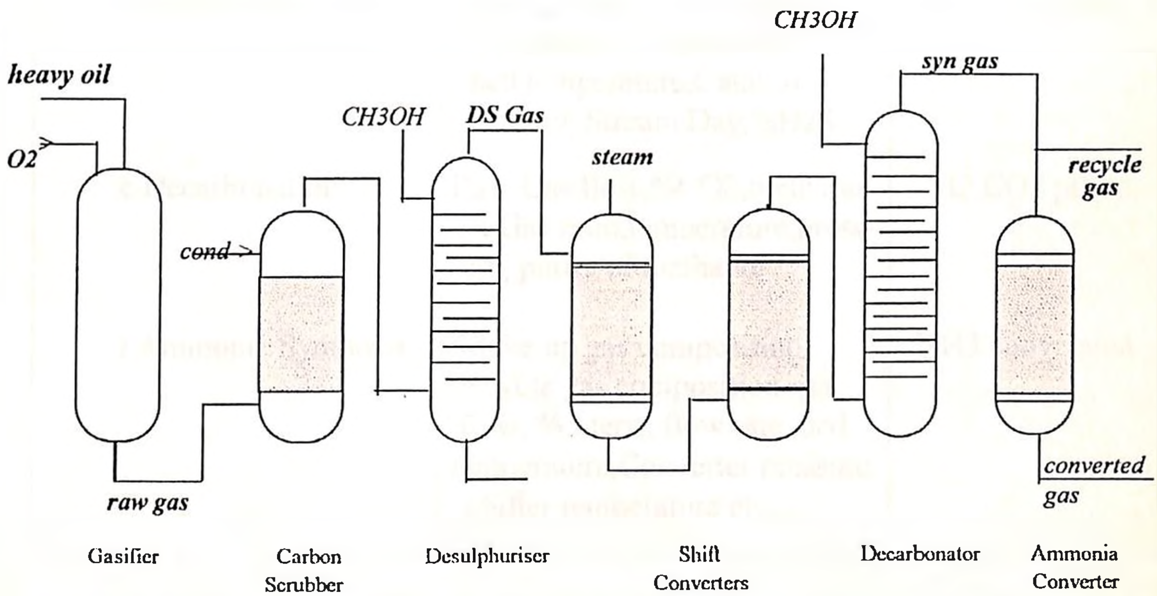
A very simple Process flow diagram of the unit is shown in **fig 5.01** in the form of blocks. The objective of the **EORT** model is to develop a *perfomance monitoring model for each section of the unit to improve the productivity of the overall industry* and determine the most critical variables from Operations point of view that may have to be monitored effectively than thousands of others. There is no doubt that the operations chief is a better judge about the Plant Operation.

Unfortunately, *there are a number of conflicting variables (at inter unit & intra unit level) which interact and affect the overall efficiency of each section and also the total process.* There are a number of micro level and macro level dynamic parameters which tend to affect the overall performance.

This is very difficult to identify even by the most experienced and expert operations manager. EORT modelling technique is capable of revealing the impact of each parameter on the output sought by the Decision Maker and *helps in taking the right combination of decisions at the right time.*

Conflicting parameters may be balanced using the model for achieving highest production & maximise profits by reducing operating cost.

Fig 5.01. Typical Process Flow Diagram - Partial Oxidation Ammonia Unit



Effect of Process Variables on Plant performance.

There are a number of process variables for each section of the plant that affect the individual performance and the performance of each individual unit ultimately affects the overall performance of the industry.Some of the typical important process variables which determine the performance of individual unit and the total process is given below.All the process variables are not covered in this.

unit	variables	decision variable
a.Gasification Section	feed rate,density,c/h ratio,oxygen to feed ratio, temperature,pressure	CO%, H2%,Carbon content.
b.Carbon Scrubber	gas flow,water scrubbing rate,temperature	scrubbing efficiency
c.Desulphuriser Section	flow rate of methanol, raw gas flow,composition, temperature,system pressure, purity of methanol etc	desulfurisation efficiency.
d.Shift Conversion	Raw gas flow, %CO in DS gas, Steam/CO mole ratio, bed temperature,Catalyst activity, Stream Day,%H2S	H2 ,CO2 prodn
e.Decarbonation	Raw Gas flow,%CO2,methanol /R.Gas ratio,temperature,press-ure, purity of methanol	H2,CO2 prodn
f.Ammonia Synthesis	Make up gas composition, recycle gas composition,gas flow, % inerts, flow rate, bed temperature,Converter pressure ,chiller temperature etc.	NH3 conversion

Note: The same analogy may be applied to any process such as Steam - Naphtha Reforming, Gas Reforming, Coal Based Gasification etc.Examples refered to here may equally be applied for other processes also.*It is the modelling approach that is more important than the process themselves.*

Variables Used in EORT models Explained

Partial Oxidation based Gasification is very complex and kinetic approach is tedious and subject to numerous computational errors. However, certain practical common observations encountered in *actual plant operation may be utilised to establish the optimal process parameters.* The main objective of partial oxidation process is to produce maximum hydrogen & carbon monoxide using heavy oil feed stock. This depends on the feed quality, oxygen to feed ratio, temperature of gasifier etc. *The controllable parameters in this process are feed quality, oxygen to feed ratio, operating pressure of gasifier etc.* EORT model may be used to determine the *maximum amount of hydrogen that could be produced by the existing system* based on actual process parameters.

Desulfurization unit is based on absorption of H_2S by the solvent methanol and the efficiency of absorption affects the performance of Shift Converter Catalyst & its life and activity. Some of the critical parameters that affect this unit process are feed rate, %H_2S in Raw Gas, solvent to feed ratio, its distribution efficiency, absorber pressure, temperature etc.

Shift Conversion reaction is based on the conversion of CO to CO_2 & H_2 by water shift reaction. In this converter, CO reacts with steam & gets converted into CO_2 & H_2. Performance of Shift Conversion has been found to be dependent on feed rate, reaction temperature, steam to CO mole ratio , catalyst activity etc. The most critical process of the industry is Shift Conversion *and this unit alone can control the economics of the total ammonia production.* A critical balance of CO_2 to H_2 has to be maintained in this process for maximising ammonia production compatible with Urea production. In many cases , it has been found that the industry has surplus CO_2 & inadequate NH_3 or the vice versa. **EORT** model helps in optimizing the ratios from observed operation parameters.

Similarly **Ammonia synthesis reaction** also depends on process parameters such as gas *composition, %NH_3 in recycle gas, H_2/N_2 ratio of make up gas , reactor pressure, temperature, catalyst condition* etc .

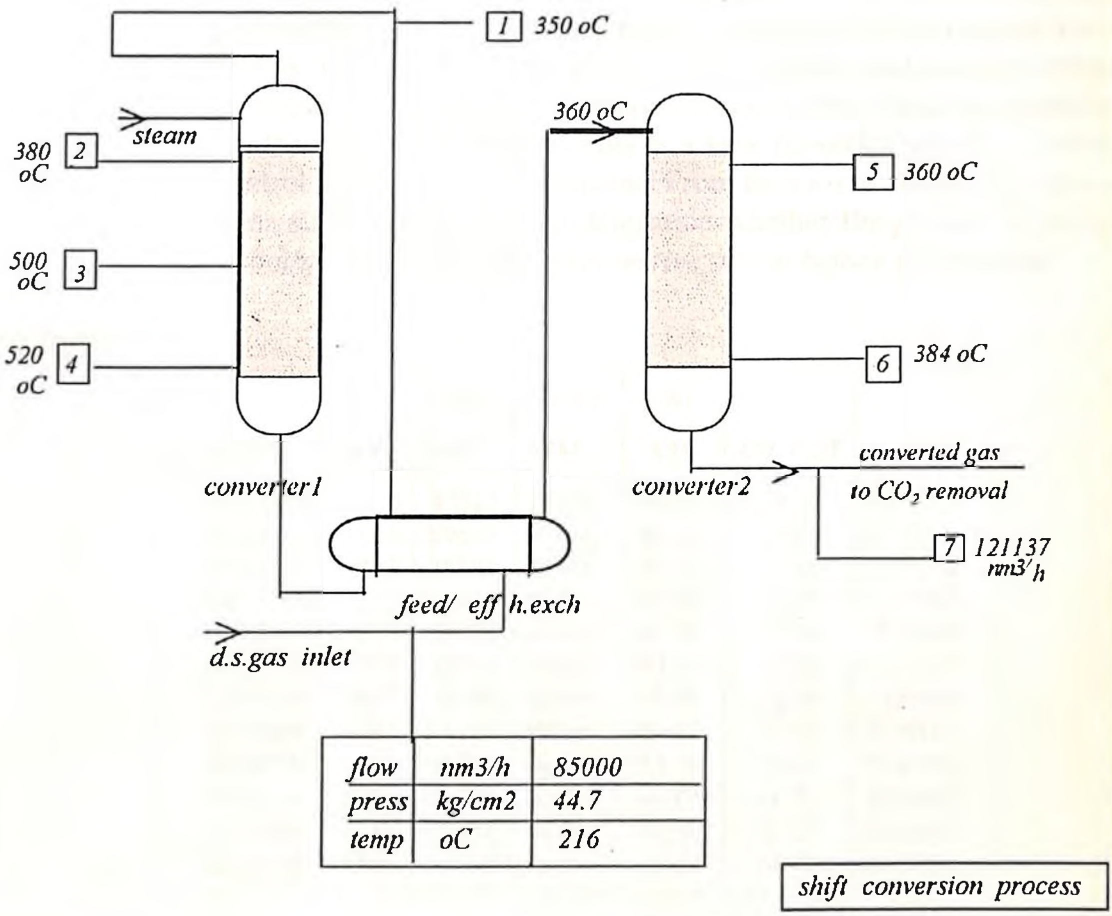
It may be understood that **EORT** models are a simple substitute to Dynamic Programming and this is a very powerful **Production Planning tool** and is based on the concept

$$prodn = f1*e1+f2*e2+f2*e3 + \ldots\ldots \text{ etc}$$

where f1,f2,f3 etc represent capacity utilsation & e1,e2,e3 etc represent conversion efficiency. **EORT** models are capable of identifying the operational constraints experienced in real life situations and very powerful decisions emerge from these models.(pl refer program outputs)

Case Study : The objective of the assignment is to determine the catalyst life used in the converters and determine the operating parameters for achieving the maximum conversion within the operating constraints.(16,17)

Fig 5.02 - Shift Converter flow diagram



Typical shift conversion design parameters for an existing fertilizer unit is given in fig 5.02. Output of EORT models for taking various operating decisions are also given in the following pages. These models may be used to determine

- *whether the converter performance is okay / or not*
- *what are the reasons for the abnormal situation?*
- *what parameteres may be manipulated to bring about the desired effect/ change.*
- *whether to continue with the existing situation or modify.*
- *whether the catalyst has to be replaced & if so when should it be replaced*
- *what is the economics of operation etc*

Basic Model: This is a very simple & basic model that may be used to determine conversion efficiency of any unit processes such as ***Shift Conversion, Ammonia Synthesis, Catalytic Reforming etc*** as a function of stream day.This is based on *actual operating data and the process analysis of incoming and outgoing streams.*Typical observations for the above unit is given below. This data forms the basic input for determining the performance of the conversion process and monitors the process trend by deviation analysis.It has been observed that catalytic conversion processes show fast deterioration at the end of the cycle & the operation tends to be uneconomical. This is a very powerful tool for quality control and cost control decisions.From the moving trend, the operations staff shall be able to determine whether the *process is going smoothly or not for taking corrective action before it is too late.*

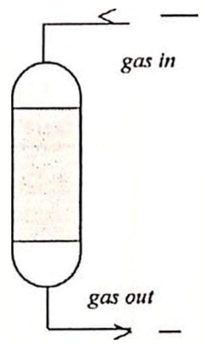
Data Input :

DATE	DAY	(nm3/h) GAS	(t/hr) STM	(%) CO	(%) CO_OUT	%CONV
07/21/86	0	87713	39.60	45.83	4.06	87.5852
11/21/86	123	89623	40.50	44.14	4.61	85.6094
02/23/87	217	88881	40.40	45.93	5.16	84.4100
09/27/87	433	90426	38.30	47.65	7.09	79.4852
12/31/87	528	90962	38.40	46.78	7.34	78.5444
09/22/88	794	88769	39.20	47.51	7.25	79.0117
12/01/88	864	93398	40.60	49.99	8.34	76.9030
03/08/89	961	94132	39.60	46.99	8.75	74.8313
06/08/89	1053	91409	40.80	51.26	10.63	71.6466
09/21/89	1158	85194	40.70	44.65	11.21	67.3443
12/14/89	1242	87962	39.00	47.76	13.20	63.9239
03/28/90	1346.	84710	38.20	49.23	14.47	61.6820

Output:

EORT program develops 4 models for the above data which is given below. These models may be used for quick estimation of conversion as a function of stream day.The program first converts the above data into the objective sought. (Estimates conversion as a function of %CO converted in the reactor. The program smoothens the gas composition from the inlet & outlet gas compositions.Then it estimates the conversion based on CO inlet moles. Then the program develops a material balance & gives the flow rate at the outlet of the first converter.This program assumes the variations in steam/co ratio, temperature profiel etc to be constant.

Example 5.01. Time Dependent Performance models



file name : a:\n2
base value for X variable : 0

model 1:

stream day	X1	conversion	
		actual	by model
0	0.0000	87.5800	88.6307
123	123.0000	85.6000	86.4777
217	217.0000	84.4100	84.8323
433	433.0000	79.4900	81.0514
528	528.0000	78.5400	79.3885
794	794.0000	79.0100	74.7324
864	864.0000	76.9000	73.5072
961	961.0000	74.8300	71.8093
1053	1053.0000	71.6500	70.1989
1158	1158.0000	67.3400	68.3610
1242	1242.0000	63.9200	66.8906
1346	1346.0000	61.6800	65.0702

STANDARD ERROR OF ESTIMATE IS : 2.3736

model 2:

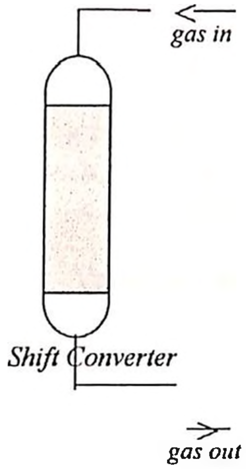
0	0.0000	87.5800	89.4537
123	123.0000	85.6000	86.9172
217	217.0000	84.4100	85.0274
433	433.0000	79.4900	80.8389
528	528.0000	78.5400	79.0627
794	794.0000	79.0100	74.2943
864	864.0000	76.9000	73.0879
961	961.0000	74.8300	71.4486
1053	1053.0000	71.6500	69.9278
1158	1158.0000	67.3400	68.2316
1242	1242.0000	63.9200	66.9043
1346	1346.0000	61.6800	65.2966

c. MODEL FORECAST FOR NEW DATA

stream day	Z1	ESTIMATED %CO Converted
linear:		
1400	1400.0000	64.1250
1450	1450.0000	63.2498
1470	1470.0000	62.8997
1480	1480.0000	62.7247
1490	1490.0000	62.5496
1500	1500.0000	62.3746
exponential		
1400	1400.0000	64.4772
1450	1450.0000	63.7277
1470	1470.0000	63.4303
1480	1480.0000	63.2821
1490	1490.0000	63.1343
1500	1500.0000	62.9868
Non-Linear		
1400	1400.0000	60.5181
1450	1450.0000	58.8393
1470	1470.0000	58.1529
1480	1480.0000	57.8065
1490	1490.0000	57.4580
1500	1500.0000	57.1074
Polynomial		
1400	1400.0000	57.1494
1450	1450.0000	53.9676
1470	1470.0000	52.6079
1480	1480.0000	51.9089

Example 5.01 given above may be used to estimate conversion efficiency of the process from the *stream day vs conversion relationship*. This is just a rough estimate and assumes all the parameters are constant.

Example 5.02. EORT model application for Shift Conversion Process



Input file: htver2.in,

Output files: htver2.otn
(This is a multi variable linear model output file created automatically by the program)

htver2.scn
(This is a multi variable non linear model,created automatically by the program)

Title: EORT Shift Conversion Model
Data sets,12
ind variables 5
bed temp oK,flow mole/s,feed %CO,steam/CO,aging,%CO converted
734.22,1.087,45.98,1.2227,1.0000,76.51
755.67,1.1107,44.33,1.2694,0.9872,80.04
753.33,1.1015,46.11,1.2275,0.9799,84.41
748.89,1.1207,47.75,1.1045,0.9688,79.49
755.67,1.1273,47.02,1.1180,0.9464,78.54
760.33,1.1001,47.66,1.1538,0.9049,79.01
773.97,1.1575,50.25,1.0772,0.8506,76.90
774.78,1.1666,47.05,1.1134,0.8312,74.83
787.00,1.1328,51.56,1.0780,0.7696,71.65
784.78,1.0632,44.71,1.3212,0.7587,67.34
788.44,1.0901,47.94,1.1516,0.7283,63.92
791.89,1.0498,49.53,1.1337,0.6942,61.68

This example refers to the same conversion process where five independent variables are considered in the model.*(36)*

These variables are

1.Average reactor bed temperature in oK
2.Flow rate of feed gas in moles/sec
3.% CO in feed
4.Steam/CO ratio (mole)
5.Aging factor

The decision variable is the % CO converted in the reactor. Two models have been developed (linear and non-linear) whose output is given in the next page.

A B C F E R T I L I Z E R S L T D

Input Details of Multi Variable Linear Model.

a.Title: Multi Variable Shift Conversion Model
b.No of data sets used in the model : 12
c.Independant variables used in the model : 5

Variables used in the model are ......

variable 1 is bed temp oC
variable 2 is flow mole/s
variable 3 is feed %CO
variable 4 is steam/CO
variable 5 is aging
variable 6 is %CO converted

observed %conversion	calculated by model 1	error term
76.51000	77.70187	-1.19187
80.04000	82.98425	-2.94425
84.41000	81.92514	2.48486
79.49000	79.63440	-0.14440
78.54000	79.11990	-0.57990
79.01000	76.03214	2.97787
76.90000	77.14288	-0.24288
74.83000	73.73492	1.09508
71.65000	72.41159	-0.76159
67.34000	66.33804	1.00195
63.92000	65.20892	-1.28893
61.68000	62.08551	-0.40551

Standard Error of the estimate = 1.65575

TSI Multi Variable Shift Conversion Model (non linear)

observed % conversion	calculated by Sci.Model	error term
76.50999	76.51437	-0.00438
80.03999	83.36092	-3.32093
84.41002	82.57349	1.83653
79.49001	79.50548	-0.01547
78.53999	79.25414	-0.71416

observed % conversion	calculated by Sci.Model	error term
79.01001	76.78177	2.22824
76.9	77.47125	-0.57125
74.83	73.15564	1.67437
71.65002	72.32914	-0.67913
67.34	66.46227	0.87774
63.92	64.87859	-0.95859
61.68	61.96748	-0.28749

Standard Error of the estimate = 1.51477

Non linear model has been found to be more accurate in this case and hence it is chosen for performance monitoring.

Relative activity of the catalyst may be expressed as a function of temperature in oK.All things remaining constant, catalyst activity will deteriorate as shown below.Similarly, the fall in catalyst activity with respect to temperature T and age of the catalyst in days may also be expressed in terms of an aging factor.EORT model estimates these deterioration functions very quickly and precisely as shown in the output. **Figs 5.04 and 5.05** explain the relative activity of the catalyst with aging. **Figs 5.06 and 5.07** show the **CO** slippage from the converter which ultimately results in loss of Ammonia Production.Under these conditions , **EORT** model helps in taking ***catalyst regeneration / replacement decision*** by the manager.

Fig 5.04 Relative Activity of the Catalyst vs Temp

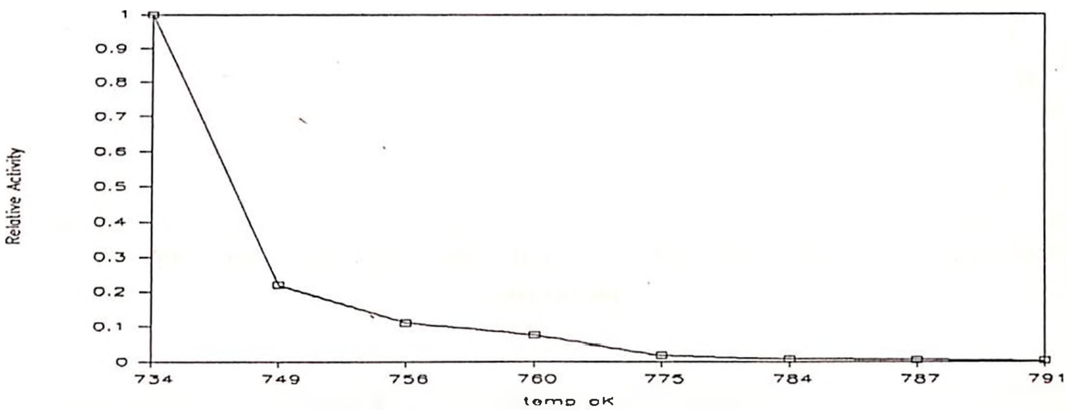
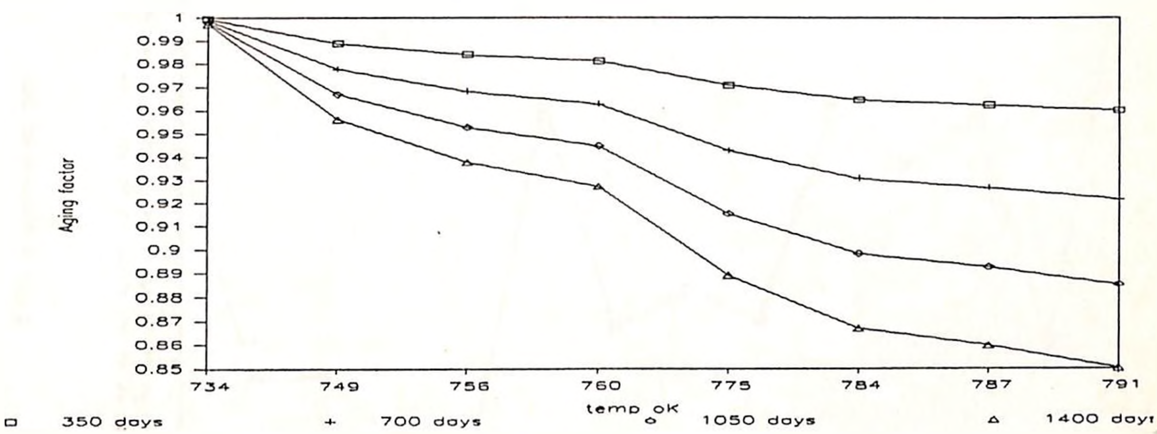


Fig 5.05. . Catalyst Aging Factor vs Temp & Stream Days

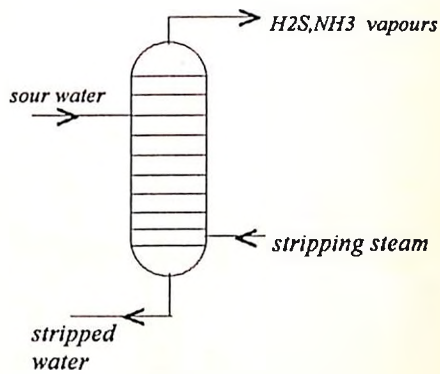


EORT Model for Sour Water Stripper Performance

Case study: Example given here refers to a ***Sour Water Stripper (36)*** which is designed to strip off the Hydrogen Sulphide, Ammonia etc from the vessel drains for recycling. While the stripped vapours are burnt off in a flare or an incinerator, excess of stripped water is routed to waste water treatment plant for removing Hydrogen Sulphide and letting it out as treated effluent. ***Stripping efficiency of the Sour Water Stripper is one major factor that determines the cost of chemicals to be used in Waste Water Treatment plant and also the success of pollution abatement measure*** . Hence there exists a need to monitor the performance of this unit continuously.

EORT model may be used for monitoring this unit which having the follwing input parameters as shown below.

```
H2S STRIPPER PERFORMANCE MODEL
24
6
flow,press,toptmp,bottmp,sstm,feedh2s,eff%
27.01 1.382 127.33 128.12 1.42 1160.00 68.97
28.23 1.552 130.56 131.78 2.92 2520.00 97.62
28.75 1.172 121.12 122.64 2.67 2880.00 96.77
28.71 1.582 127.87 129.65 3.50 5280.00 93.94
26.66 1.562 127.88 130.38 2.00 2890.00 87.20
27.05 1.442 127.40 129.81 2.00 2400.00 85.00
28.06 1.202 124.73 125.77 4.46 3200.00 96.25
28.39 1.242 124.03 125.29 4.08 4000.00 94.00
28.51 1.552 129.47 130.98 4.21 3360.00 91.67
28.64 1.622 132.77 134.47 4.60 4800.00 97.50
27.79 1.442 127.20 128.86 4.10 3200.00 93.13
28.29 1.592 129.40 131.00 4.50 4900.00 95.92
28.66 1.392 126.87 128.54 4.50 5000.00 94.40
28.35 1.282 124.89 127.13 4.41 6400.00 95.38
26.41 1.402 126.89 128.54 4.25 3820.00 90.58
26.50 1.412 131.72 133.38 4.55 6280.00 92.36
26.67 1.572 131.04 133.20 4.38 6160.00 91.56
26.29 1.402 126.63 128.46 4.40 5200.00 93.85
26.44 1.662 129.09 131.28 4.50 6880.00 92.44
24.67 1.122 124.10 125.72 3.45 5360.00 91.79
27.34 1.152 120.25 121.96 4.01 3400.00 95.29
27.24 1.152 118.59 120.73 4.01 5680.00 91.55
26.60 1.132 121.01 122.41 4.01 4200.00 93.33
27.42 1.142 122.32 124.38 4.01 5080.00 93.70
```



Sour Water Stripper

Variables that affect stripping efficiency are stripper operating pressure, Feed water rate, top temperature , bottom temperature, H2S % in feed and Stripping steam rate . Program output is given in the next page.

SWS STRIPPER PERFORMANCE MODEL

b.No of data sets used in the model : 24
c.Independant variables used in the model : 6

Variables used in the model are ......

variable 1 is flow
variable 2 is press
variable 3 is toptmp
variable 4 is bottmp
variable 5 is sstm
variable 6 is feedh2s
variable 7 is eff%

SCIENTIFIC MODEL OUTPUT
(Non Linear)

solution for the model ....

1	coefficient:	0.57935
2	coefficient:	-0.10094
3	coefficient:	-2.65851
4	coefficient:	2.82965
5	coefficient:	0.13099
6	coefficient:	0.02328
7	coefficient:	1.40662

MUTIPLIER (last value) IS 4.082133

observed efficiency	*simulated eff% by Sci.Model*	*error term*
68.97000	76.76771	-7.79770
97.62000	88.25828	9.36171
96.77001	90.62231	6.14769
93.94001	93.53077	0.40924
87.20001	83.51310	3.68691
85.00000	84.33193	0.66807
96.24999	94.91360	1.33639
94.00002	95.02202	-1.02201
91.67000	94.22322	-2.55323
97.50002	96.66518	0.83484

observed efficiency	*simulated eff% by Sci.Model*	*error term*
93.12997	93.17822	-0.04824
95.92002	95.39137	0.52864
94.40001	97.35739	-2.95739
95.38000	98.89956	-3.51955
90.58002	91.48066	-0.90064
92.35999	93.98737	-1.62738
91.56000	93.74075	-2.18076
93.85002	92.65681	1.19320
92.44000	93.20315	-0.76314
91.79002	87.88544	3.90458
95.28999	93.67918	1.61081
91.55000	95.38983	-3.83983
93.32998	92.23473	1.09524
93.70000	95.77660	-2.07660

Standard Error of the estimate = 3.49052

Above model may be used to carry out sensitivity analysis of the system by using the new parameters to be fitted in the model.

Sensitivity Analysis using EORT model:

A sensitivity analysis has been carried out to determine the impact of
a.operating pressure of stripper and
b.stripping steam rate to stripper on stripping efficiency. These are given in **fig 5.08 and 5.09** respectively.

It may be noted that as the stripper pressure increases, efficiency of stripping comes down and lowering of pressure increases the efficiency which is in tune with theory. It may also be noted that all parameters remaining constant, if the stripping steam rate is increased, stripping efficiency increases and at 5.5 t/hr, the efficiency is the highest for the entire operating range. This is also in tune with stripping theory.

Standard error level of the model is 3.39% which is reasonably low .The model may further be improved upon by reducing some of the redundant variables.

Fig 5.08 Sour Water Stripper Performance

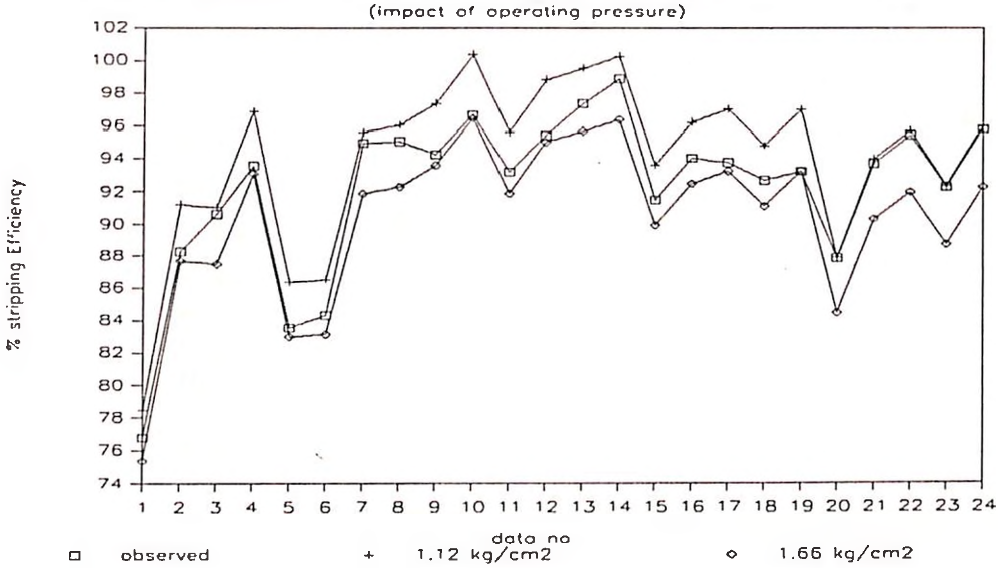


Fig 5.09 Impact of Stripping Steam Rate

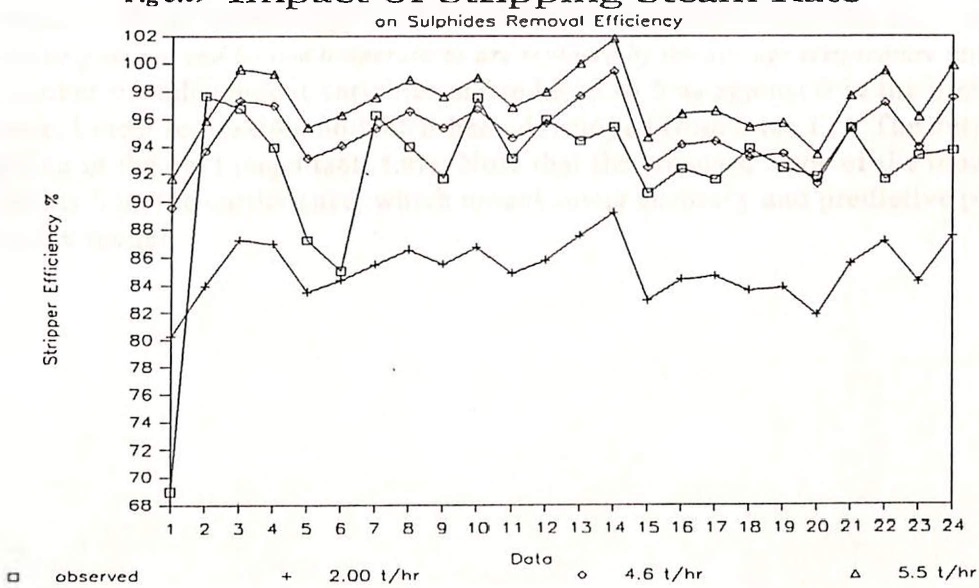


Fig 5.10 **Sour Water Stripper Performance**

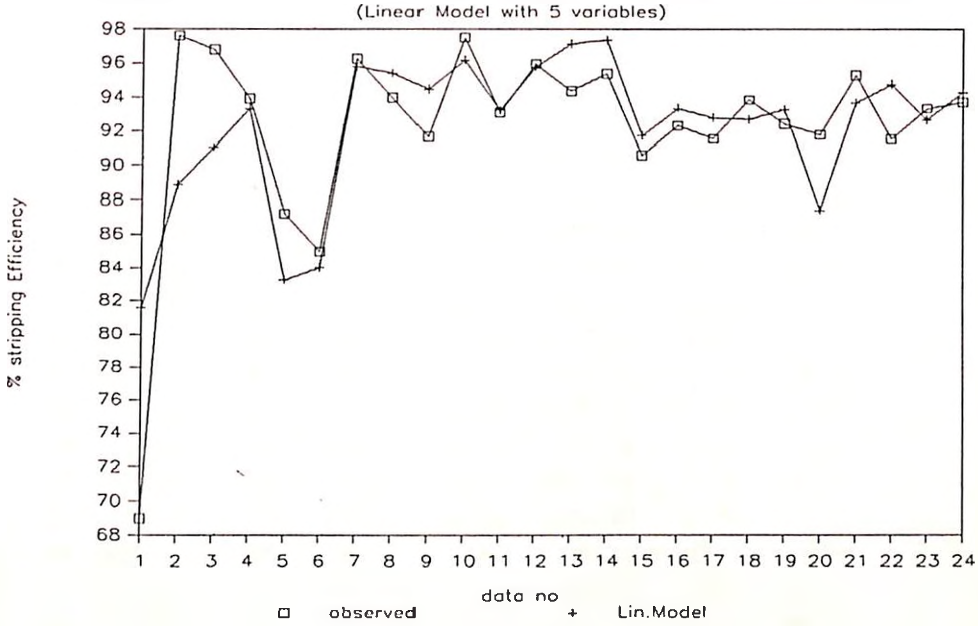


Figure 5.10 gives the Stripper Performance Model for the observed data. In this, *the stripper top and bottom temperatures are replaced by the average temperature* and the number of independent variables are reduced to 5 as against 6 in the previous case. Linear regression model has been developed from lotus 123. The output is given in the next page(**table 5.01**). Note that the standard error of the model is higher than the earlier case, which means lower accuracy and predictive power of the model.

Table 5.01 SWS STRIPPER PERFORMANCE - LINEAR MODEL (5 VAR)

Item	feed t/hr	press kg/cm2	avg temp 0C	press kg/cm2	H2S ppm	EFF % obs	By model
1	27.01	1.38	127.73	1.42	1160.00	68.97	81.58
2	28.23	1.55	131.17	2.92	2520.00	97.62	88.90
3	28.75	1.17	121.88	2.67	2880.00	96.77	91.04
4	28.71	1.58	128.76	3.50	5280.00	93.94	93.35
5	26.66	1.56	129.13	2.00	2890.00	87.20	83.31
6	27.05	1.44	128.61	2.00	2400.00	85.00	84.05
7	28.06	1.20	125.25	4.46	3200.00	96.25	95.78
8	28.39	1.24	124.66	4.08	4000.00	94.00	95.40
9	28.51	1.55	130.23	4.21	3360.00	91.67	94.48
10	28.64	1.62	133.62	4.60	4800.00	97.50	96.16
11	27.79	1.44	128.03	4.10	3200.00	93.13	93.24
12	28.29	1.59	130.20	4.50	4900.00	95.92	95.76
13	28.66	1.39	127.71	4.50	5000.00	94.40	97.15
14	28.35	1.28	126.01	4.41	6400.00	95.38	97.34
15	26.41	1.40	127.72	4.25	3820.00	90.58	91.73
16	26.50	1.41	132.55	4.55	6280.00	92.36	93.37
17	26.67	1.57	132.12	4.38	6160.00	91.56	92.81
18	26.29	1.40	127.55	4.40	5200.00	93.85	92.70
19	26.44	1.66	130.19	4.50	6880.00	92.44	93.28
20	24.67	1.12	124.91	3.45	5360.00	91.79	87.38
21	27.34	1.15	121.11	4.01	3400.00	95.29	93.68
22	27.24	1.15	119.66	4.01	5680.00	91.55	94.74
23	26.60	1.13	121.71	4.01	4200.00	93.33	92.68
24	27.42	1.14	123.35	4.01	5080.00	93.70	94.29

Regression Output:

Constant	48.5865				
Std Err of Y Est	4.38737				
R Squared	0.55				
No. of Observations	24.00				
Degrees of Freedom	18.00				
X Coefficient(	1.77	-1.66	-0.14	3.54	0.00
Std Err of Coe	1.02	11.96	0.56	1.56	0.00

From these examples, it is obvious that EORT models help in optimisation of process parameters for achieving high operational efficiency and better performance, than conventional methods.

While the EORT model applications given earlier refer to micro level problems, the technique may be extended to macro systems also. A typical case study is given below in which the analysis of a fairly macro level system is considered.(ref 60)

Case Study: This refers to a small power consuming sector such as a SSI belt which consumes about 100 mw power/hr on an average. Between consuming centre and power generation centre, there are a number of intermediaries who transmit the power to the consumers. At each stage of transmission / handling , there exists an energy loss which could be controlled by appropriate measures. The exercise is to determine what will be the maximum achievable efficiency of the total system, when all the intermediate systems are operating efficiently. This is a real *dynamic problem* faced by developing countries like India. EORT model was applied in this case and certain decisions emerged from the quantitative outputs.

Energy losses encountered in actual system include

* Efficiency level of equipment used at consumer end
* Transmission and distribution losses
* Efficiency of turbo generator
* Efficiency of power boiler.

Though the elements given above refer to a simple system, never the less the energy efficiency of each element ultimately determines the overall efficiency of the system. In conventional technique of determining the overall efficiency of the system, product of individual efficiency could be considered. But individual efficiency of the subsystem is not essentially linear in view of the unaccounted energy loss at various stages. Hence, EORT modelling methodology could be applied with ease in such cases. A typical decision flow diagram is given in fig 5.11 which describes the methodology of evaluating the overall performance of the total system. Fig 5.12 represents a typical energy flow diagram.

This methodology is used to determine the maximum achievable efficiency of the overall system and how technological options could be incorporated by retrofitting / revamping to improve the overall efficiency of the system . It is even possible to evaluate the various technological options by this method to select the best operating technology. While tables 1 through 5 represent the energy input and output levels, figs 5.13 and 5.14 represent the various options that could be considered for efficiency improvement based on EORT analysis.

Fig. 5.11 Decision Flow Diagram for Energy Efficiency Monitoring

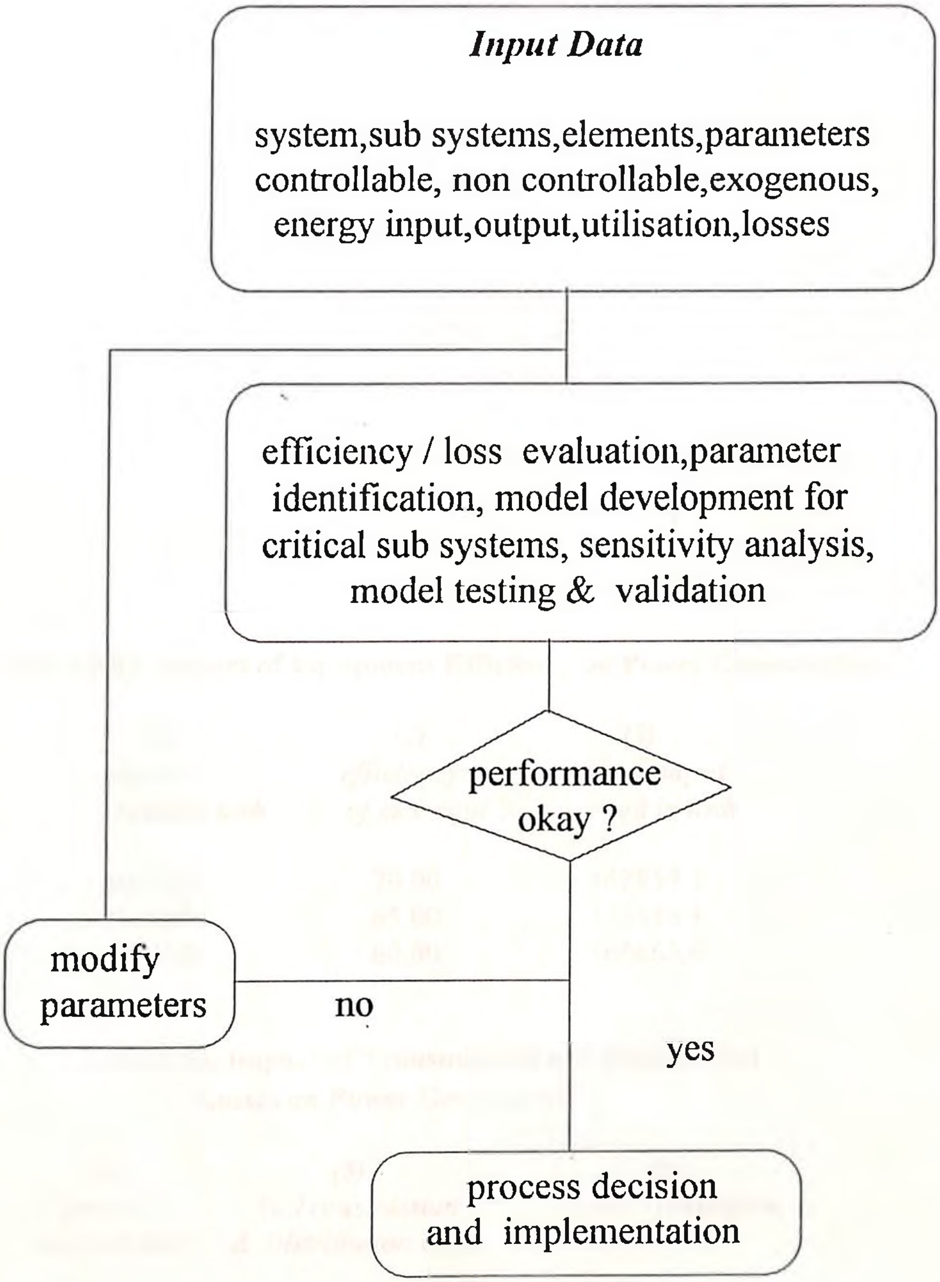


Fig 5.12 Energy Performance Monitoring Cycle for a power Generation Plant

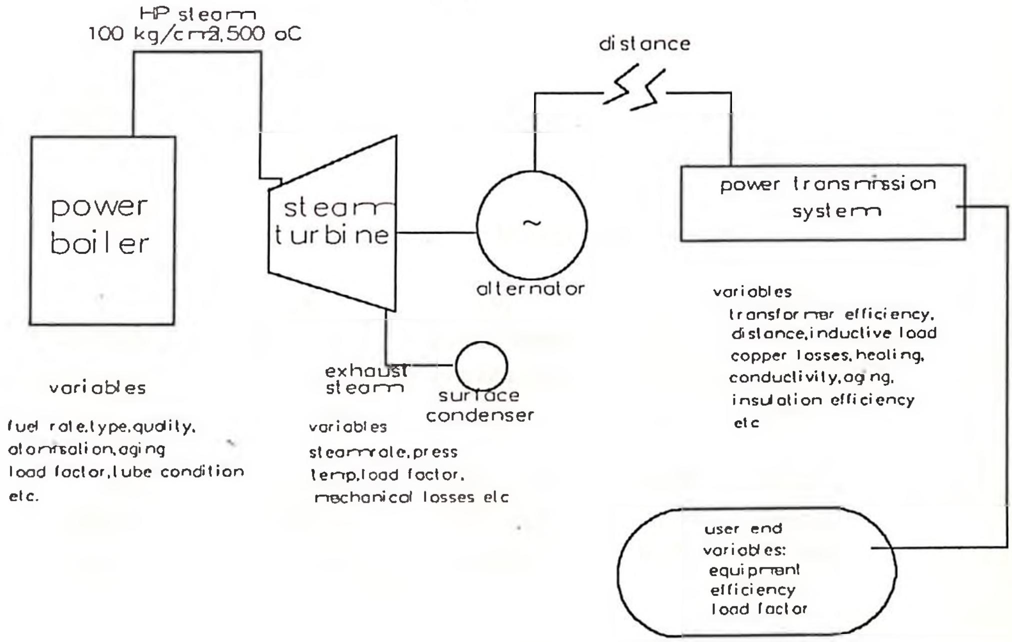


Table 5.02. Impact of Equipment Efficiency on Power Consumption.

(1) power required kwh	*(2) efficiency of elec eqpt %*	*(3) power input reqd in kwh*
100000	70.00	142857.1
100000	65.00	153846.1
100000	60.00	166666.6

Table 5.03. Impact of Transmission and Distribution Losses on Power Generation.

(4) power required kwh	*(5) % Transmission & Distribution looss*	*(6) Power Generation reqd in kwh*
142857.1	15.00	168067.2
153846.1	15.00	180995.5
166666.6	15.00	196078.4

Table 5.04. Steam Input Data to Turbo Generator

(4) power generation (kwh)	*(5) combined eff of turbo generator %*	*(6) steam input for power generation t/h*
168067.2	71.25	557.98
180995.5	66.50	643.82
196078.4	61.75	751.12

Table 5.05. Steam Load Data for Power Generation.

(7) Steam input to turbine (t/hr)	*(8) Internal consumption (t/hr)*	*(9) Total Steam generation (t/hr)*	*(10) boiler efficiency %*	*(11) fuel used in t/hr*
557.98	55.80	613.78	91.0	53.14
643.82	64.38	708.20	91.0	61.32
751.12	75.11	826.23	91.0	71.54

Table 5.06 . Overall Efficiency of the system .

(12) Fuel Consumed in t/hr	*(13) power eqvt in kwh*	*(14) power avail-able kwh*	*(15) overall efficiency %*
53.14	618007.6	100000	16.1810
61.32	713085.7	100000	14.0235
71.54	831933.3	100000	12.0202

Overall efficiency model.

$$\text{overall eff \%} = 2.160613\text{E-}05 * (\text{eff4})^{.69742} * (\text{eff3})^{1.01874} * (\text{eff2})^{1.34877} * (\text{intl})^{-.31198} * (\text{eff1})^{0.22199}$$

Standard Error of the model = 0.11989

i. Maximum Achievable Overall efficiency

1.Boiler efficiency	93.5%
2.Turbo generator efficiency	75.0%
3.Transmission & distribution efficiency	92.0%
4.Equipment efficiency of user	75.0%

Maximum overall efficiency
for long distance transmission **19.83395 % (by model)**

Case 2 :

Boiler efficiency	93.5%
Turbo generator efficiency	75.0%
Transmission & distribution efficiency	96.0%
Equipment efficiency of user	78.0%

Estimated Overall
efficiency of the system
(local power stn @ consumer end) **21.28719 %**
(by model)

Other Alternates:

A critical micro analysis of the sub sustem (industry) will reveal that most of the electrical power is used basically in mechanical drives such as pumps , compressors ,blowers etc and only a very low % for lighting purposes.

This gives rise to the following options on energy utilisation.

a.Combined heat power cycle (extraction steam to process)
b.Maximise Conversion of electrical drives to steam drives
c.Conversion of existing system to gas-turbine mode with co-generation using the existing facility (fig 5.13)
d.Incorporation of Organic Rankine Cycle to the existing power generation system.(fig 5.14)

Option c could be used for enhancing the efficiency of the overall system as given in fig 5.13.

It may be noted that ***EORT model output*** on overall efficiency of the system was used to arrive at this decision and options .

Fig 5.13 . Retrofit of existing system for increasing the overall cycle efficiency

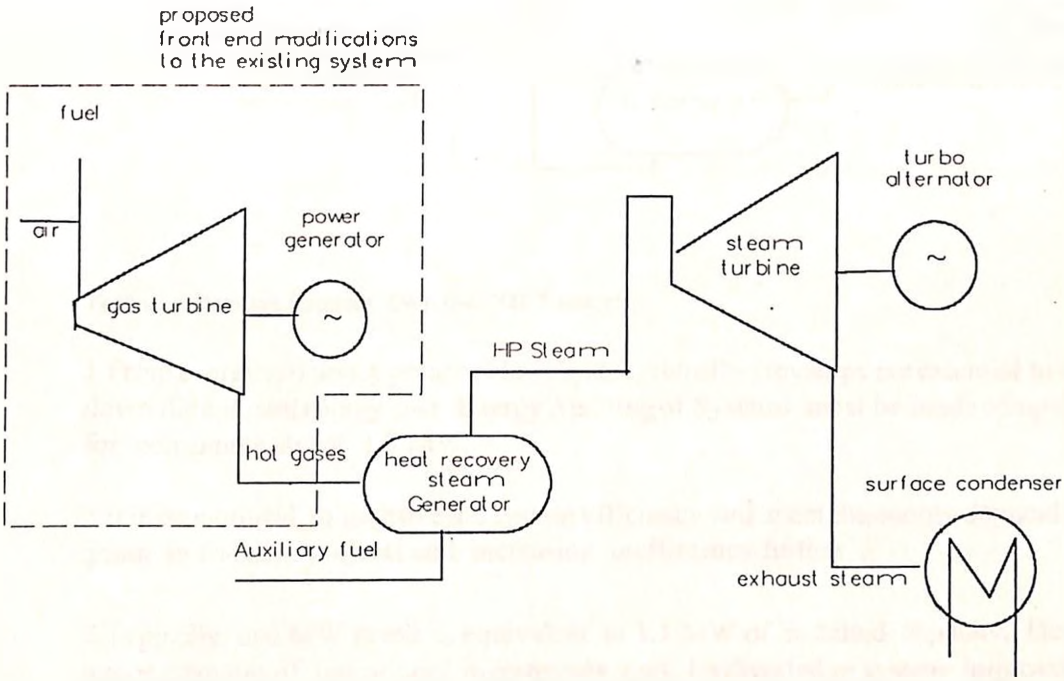
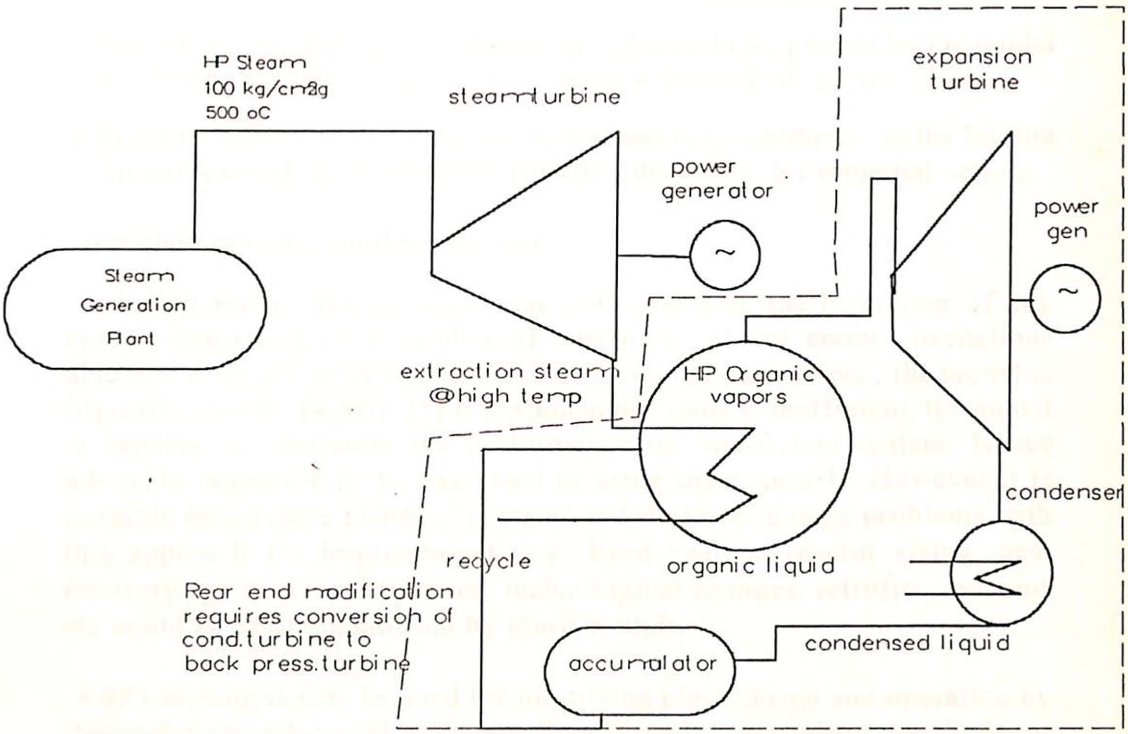


Fig 5.14 Combining Organic Rankine Cycle to the existing system for achieving higher overall cycle efficiency.



Technical Decision Support from the EORT models:

1.From energy efficiency point of view, system retrofits/revamps are essential to bring down the colossal energy loss. Energy Auditing of Systems must be made compulsory for consumers above 1.0 MW.

2.It is economical to improve the system efficiency and meet the energy demand than going in for new projects and increasing inefficiency further .

3.Typically, one MW saved is equivalent to 1.5 MW of installed capacity. Hence a major quantum of our project investments may be diverted to system improvement . Besides savings in the energy , pollution levels could also be reduced drastically by this approach .

4.All future Thermal Power Projects should be based on combined cycle and not on Rankine Cycle alone.From Energy mix point of view, hydel power projects should be given priority over thermal power projects.

5.In view of the high overall efficiency achievable as proved by the model , all industrial belts may have their own independant power plants

6.Transmission and Distribution losses must be minimised to the Interna -tional level of 8 % and power thefts identified for remedial action.

Limitations of EORT model applications:

Though EORT has the advantages of predicting the behaviour of any system consisting of a number of variables , it has certain limitations also.Since the model is heavily built on observed parameters , the model is logically system specific. If the system under study is inefficient, the model is capable of predicting the performance of inefficient system. Hence adequate caution must be exercised in using these models. However it is possible to compare identical systems and diagnose design problems with this approach for improvement (e.g. fired heaters, reactor sizing, heat recovery system etc). Impact of technological changes, retrofits, revamps etc could be easily diagnosed by these models.

EORT technique may be used for improving plant design and operation by taking the variables used in conventional simulation packages as the input and developing the model for various conditions. This approach serves to improve the technology as EORT offers the best solution for design, operation and control strategies. This approach is very widely used by foreign consultancy agencies to diagnose problem areas more effectively for trouble-shooting and improvement . Success rate of EORT modeling route is found to be very high and is extensively used in DIDC controls also.

Conclusions:

Examples related to fertilizer, process and power industry were given in this chapter , just to indicate how EORT modeling technique may be used for taking unit level operation and national level energy management decisions which has tremendous impact on *'unit level profitability'* and *'national economy'* . This has direct impact on *' industrial productivity ' and ' national income '*.

PRODUCTION PLANNING MODELS

Chapter 6. Production Planning Models

Production section of the industry is the real cost centre that has to be monitored very meticulously by every one concerned. For sustaining efficient production, production planning must be carried out carefully. When the process has high complexity and diverse products are produced, the problem becomes all the more complex. *Mere quantity of production or throughput processed* by a process industry does not necessarily mean efficient operation though high capacity utilisation tends to reduce the operating cost and increase profits.

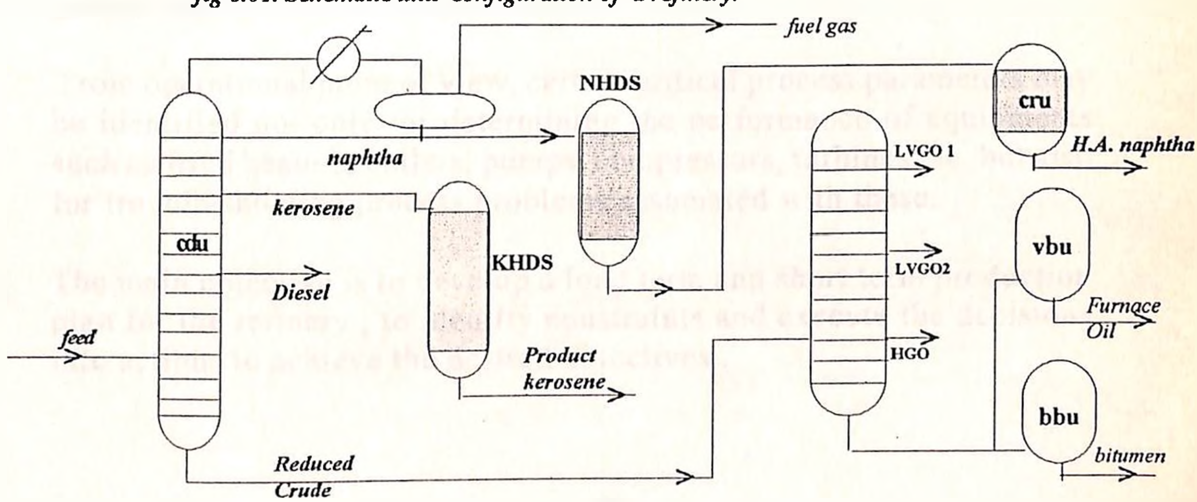
In a complex process industry such as the petroleum refinery, comprising of a number of secondary conversion and treatment processes, the situation is so dynamic that the **optimal solution for one feed / product / process mix doen not hold good for the other.** Hence the production manager has to take right decisions for improving the productivity of the industry considering the intensity of several constraints.

Under these conditions, computer-aided production planning becomes very handy for taking appropriate decisions at all levels. Combining operational and process engineering experience and expertise, certain decision rules could be developed and transformed into quantitative models for diagnosing process problems. The basic approach adopted in such situations is the system analysis which comprises of inputs and outputs.*(Ref 16,18,33,34)*

Case Study:

This refers to the production planning system of a refining industry *(ABC petroleum corporation ltd.).* This coastal refinery was set up in 1966 in South India.

fig 6.01. Schematic unit configuration of a refinery.



This refinery comprises of the following major units and the configuration is as given in fig 6.01 .

1.Crude Distillation Unit (CDU)
2.Vacuum Distillation unit (VDU)
3.Naphtha Hydro Desulfurisation Unit (NHDS)
4.Kerosene Hydro Desulfurisation unit. (KHDS)
5.Catalytic Reforming Unit (CRU)
6.Visbreaker Unit (VBU)
7.Bitumen Unit (BBU)
8. Aromatics Unit (ARU)

This refinery is intended to process high sulfur as well as sweet crudes to produce the following products.

1.Naphtha
2.High Aromatic Naphtha
3.Gasoline
4.ATF / MTO
5.Superior Kerosene
6.Diesel Oil
7.Furnace Oil
8.Bitumen
9.Low Sulfur Heavy Stock
10.LDO
11.Aromatics from HA Naphtha.

Each unit has a specific purpose with respect to product quality to be attained by the above products. Fuel Gas coming out of the process units is used as internal fuel .

From operational point of view, certain critical process parameters may be identified not only for determining the performance of equipments such as fired heaters, boilers, pumps, compressors, turbines etc. but also for trouble-shooting process problems associated with these.

The main objective is to develop a long term and short term production plan for the refinery , to identify constraints and execute the decisions into actions to achieve the desired objectives .

Demand forecast by EORT models:

Production plan for the above refinery is the foremost step to be carried out to determine

1. What should be the unit processing capacity ?
2. What are the products to be produced ?
3. What feed mix is to be used ?
4. What will be the impact of each unit capacity on overall product pattern ?
5. What are the requirements of utilities ?
6. What will the process loss ?
7. What is the profitability of the chosen mode of operation etc.

Production planning of the system starts with short term and long term demand forecast. This information is normally retrieved from marketing or sales information or government survey reports , bulletins etc. From this information, the planner works back and estimates the planning activities. A decision flow diagram as given in fig 6.02 explains the various steps involved in the planning mechanism.

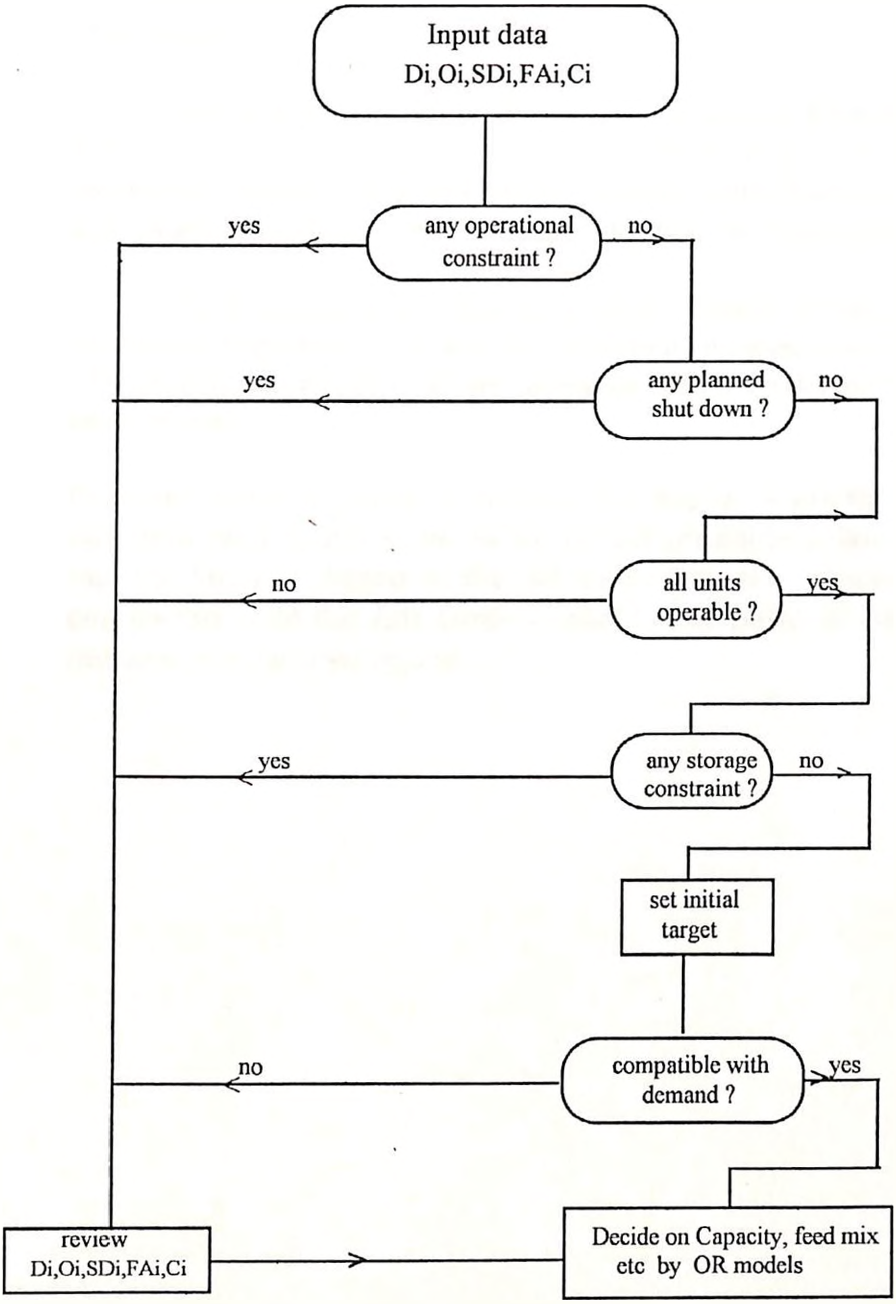
Using *fore casting models*, futuristic demand for various products may be determined with reasonable accuracy. Though conventional forecast predictions are based on linear model, we will generate four models to determine the best that suits the situation.

The program output given refers to the demand pattern for petroleum products.Using the product pattern variations, production planning strategy could be worked out.

This case study refers to a petro chemicals refinery which produces conventional petroleum products , aromatics and some speciality products . The feed rate processed and the products produced during the years 1989 to 1995 forms the basis for the program .

Due to monopolistic situation, it is presumed that production equals demand. On this basis, a production plan will be developed for the next 5 years (i.e 1995 to 2000) *using computer-aided programs* . **This forecast will form the decision base** for choosing the *appropriate process mix , extra processing capacity / capability, additional facilities required , cost investments and profitability of operation.*

Fig 6.02. Decision flow diagram for unit level operational planning.



(Di,Oi,SDi,FAi,Ci are demand,shut down, operational constraint, equipment availability & storage constraints respectively)

Methodology:

Methodology adopted in this case is very simple. First phase of the study is the data collection .This has been done in detail as given in the **table 6.01** . For **petroleum demand forecast,** four models have been developed namely *linear, exponential, quadratic and polynomial* using conventional regression techniques.

For determining the individual product demand, linear regression models have been employed using **lotus 123** to estimate the percentage of each product . These models are used in the **product forecast model** to fix the production target for each product.

Program output is given in the next few pages. While **Fig 6.03** depicts the output of each model based on the actual production data , **fig 6.04** shows the the forecast, based on the polynomial model which is found more compatible with the data from standard error point of view.

(Ref 4,5,10,12,20,24,33,34,36,37,39,54,59)

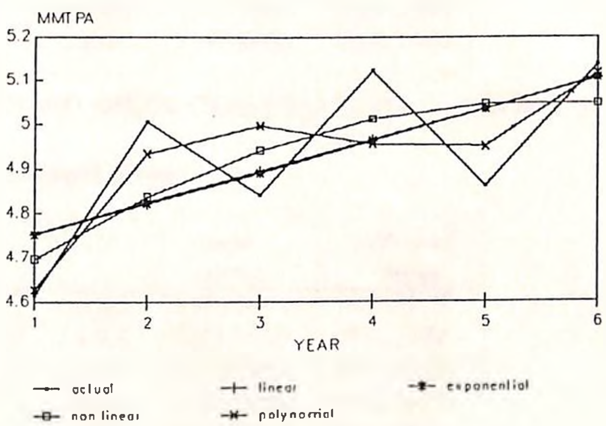
Table 6.01 Petroleum Processing and Consumption Data for the program

('000 tons/yr)

	year	feed ind	feed imp	total	L.dist	M.dist	Hy.dist	pfl	lpg
1	89-90	3222.4	1393.8	4616.2	840.7023	2727.2510	625.0335	271.4326	151.78
2	90-91	3669.1	1335.9	5005.0	830.8000	3052.5495	655.6550	285.7855	180.21
3	91-92	3583.9	1257.9	4841.8	889.6469	2835.3581	631.8549	304.0892	180.85
4	92-93	3616.5	1505.8	5122.3	967.0595	2906.3930	755.0270	305.8013	188.02
5	93-94	3453.0	1408.5	4861.5	928.1479	2766.1935	690.3330	291.2039	185.62
6	94-95	3913.5	1222.5	5136.0	1171.7424	2752.3824	707.7408	313.7069	190.43

LPG %	L.dist %	m.dist %	hy.dist %	pfl %	total (recon)
3.2880	18.2120	59.0800	13.5400	5.8800	4616.199
3.6006	16.5994	60.9900	13.1000	5.7100	5004.999
3.7352	18.3743	58.5600	13.0500	6.2805	4841.799
3.6706	18.8794	56.7400	14.7400	5.9700	5122.300
3.8182	19.0918	56.9000	14.2000	5.9900	4861.498
3.7077	22.8143	53.5900	13.7800	6.1080	5136.002

Fig 6.03 Forecasting Models for Production Planning



(based on live data)

ABC Petroleum Corporation Ltd

a.Input Details of the model

file name : b:\fcstcrud
base value for X variable : 0

b.Input Data

X values year	Y values '000 tpy
1	4616.2002
2	5005.0000
3	4841.7998
4	5122.2998
5	4861.5000
6	5136.0000

c.PROGRAM OUTPUT

Forecasting for Petroleum Demand (crude)

A.Linear Model

year	X1	actual '000 tpy	Simulated '000 tpy
1	1.0000	4616.2002	4755.5396
2	2.0000	5005.0000	4825.5107
3	3.0000	4841.7998	4895.4814
4	4.0000	5122.2998	4965.4521
5	5.0000	4861.5000	5035.4233
6	6.0000	5136.0000	5105.3940

STANDARD ERROR OF ESTIMATE IS : 135.5856

B.Exponential Model

year	*X1*	*actual '000 tpy*	*simulated '000 tpy*
1	1.0000	4616.2002	4753.3979
2	2.0000	5005.0000	4822.1382
3	3.0000	4841.7998	4891.8726
4	4.0000	5122.2998	4962.6157
5	5.0000	4861.5000	5034.3813
6	6.0000	5136.0000	5107.1855

STANDARD ERROR OF ESTIMATE : 136.0062

C.Non-Linear Model

year	X1	actual '000 tpy	simulated '000 tpy
1	1.0000	4616.2002	4698.2866
2	2.0000	5005.0000	4836.9609
3	3.0000	4841.7998	4941.2837
4	4.0000	5122.2998	5011.2544
5	5.0000	4861.5000	5046.8735
6	6.0000	5136.0000	5048.1411

STANDARD ERROR OF ESTIMATE : 128.6377

D.Polynomial Model

year	X1	actual '000 tpy	simulated '000 tpy
1	1.0000	4616.2002	4629.3750
2	2.0000	5005.0000	4933.4443
3	3.0000	4841.7998	4996.4141
4	4.0000	5122.2998	4956.1182
5	5.0000	4861.5000	4950.3892
6	6.0000	5136.0000	5117.0610

STANDARD ERROR OF ESTIMATE : 104.1439

E. SIMULATED FORECAST

i.Linear Model

year	Z1	forecast '000 tpy
7	7.0000	5175.3652
8	8.0000	5245.3359
9	9.0000	5315.3066
10	10.0000	5385.2778

ii.Exponential Model

year	Z1	forecast '000 tpy
7	7.0000	5181.0420
8	8.0000	5255.9668
9	9.0000	5331.9751
10	10.0000	5409.0825

iii.Non-Linear Model

year	Z1	forecast '000 tpy
7	7.0000	5015.0566
8	8.0000	4947.6206
9	9.0000	4845.8330
.10	10.0000	4709.6938

iv.Polynomial Model

year	Z1	forecast '000 tpy
7	7.0000	5593.9658
8	8.0000	6518.9375
9	9.0000	8029.8091
10	10.0000	10264.4131

Model Coefficients:

1.LINEAR MODEL Y= M1*X1+C
M1= 69.97089 :C1= 4685.569

2.EXPONENTIAL MODEL y = a* E^BX
a= 4685.637:B= 1.435775E-02

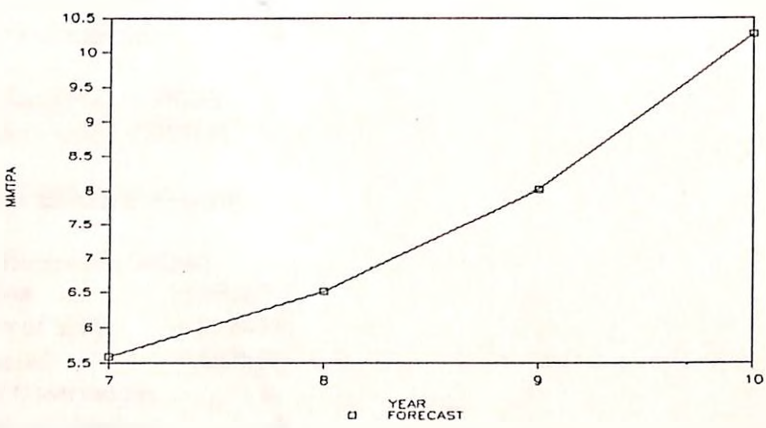
3.NON-LINEAR QUADRATIC MODEL y= A2*X1^2+B2*X1+C2
A2 =-17.17585 : B2 = 190.2018 :C2 = 4525.261

4.POLYNOMIAL MODEL y= A3*X1^3+B3*X1^2+C3*X1+D3
A3 = 22.97219 :B3 =-258.3826:C3 = 918.4114:D3 = 3946.374

Choosing the appropriate model for forecast :

This is the most important part of selecting the model for futuristic demand prediction. For choosing the appropriate model from the above four models , *standard error criteria may be used (Ref 1,4,5).* It may be noted that the standard error levels of linear ,exponential ,quadratic and polynomial models are 135.5856 ,136.0062 ,128.6377 and 104.1439 respectively. Since the minimum value of SE is noted in the case of polynomial model, this may be considered as the best model for forecasting. Hence, production plans will be based on this forecast data. **Fig 6.03** shows the closeness of each model to the observed data .**Fig 6.04** gives the forecast for next five years based on the polynomial model .

Fig 6.04 Production forecast based on Polynomial Model



Production Planning :

Using the forecast value of polynomial model (in this case) annual feed rate to be processed is established. Applying the standard error correction, the final production figures are determined. *Using this value, and the planned number of stream days , pro rated processing rate per stream day is established* . From this value , the product pattern is determined using the product demand, which is again retrieved from the linear regression models. Ultimately, this becomes the production target for the organisation and forms the basis for other activities. Using Product demand pattern models , planned product pattern are given in **table 6.02**, yearwise , using linear regression models *(Ref 37,38,39)* .

1.Crude Processing Estimate

Regression Output:	
Constant	4685.566
Std Err of Y Est	166.0578
R Squared	0.437185
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	69.97142
Std Err of Coef.	39.69542

2. LPG % estimate

Regression Output:	
Constant	3.368021
Std Err of Y Est	0.130950
R Squared	0.600580
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	0.076769
Std Err of Coef.	0.031303

3. Light distillate estimate

Regression Output:	
Constant	15.89582
Std Err of Y Est	1.380576
R Squared	0.642856
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	0.885537
Std Err of Coef.	0.330020

4. Middle Distillate estimate.

Regression Output:	
Constant	61.79733
Std Err of Y Est	1.346431
R Squared	0.772697
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-1.18685
Std Err of Coef.	0.321858

5.Heavy distillate estimate.

Regression Output:	
Constant	13.116
Std Err of Y Est	0.630748
R Squared	0.255931
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	0.176857
Std Err of Coef.	0.150777

6. PFL estimate.

Regression Output:	
Constant	5.8228
Std Err of Y Est	0.193259
R Squared	0.210436
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	0.0477
Std Err of Coef.	0.046197

From the regression coefficient point of view, demand pattern for Heavy distillate and PFL are not found satisfactory . However, the demand for these two products will not have appreciable impact on production plan as the total contribution of these work out to 20.0% only and even a variation of 10% may be accommodated in the planning model.

These coefficients and constants along with that of feed rate prediction model (polynomial type) may be used to predict the product demand pattern using either lotus or any other program *(Ref 37,38,39).*

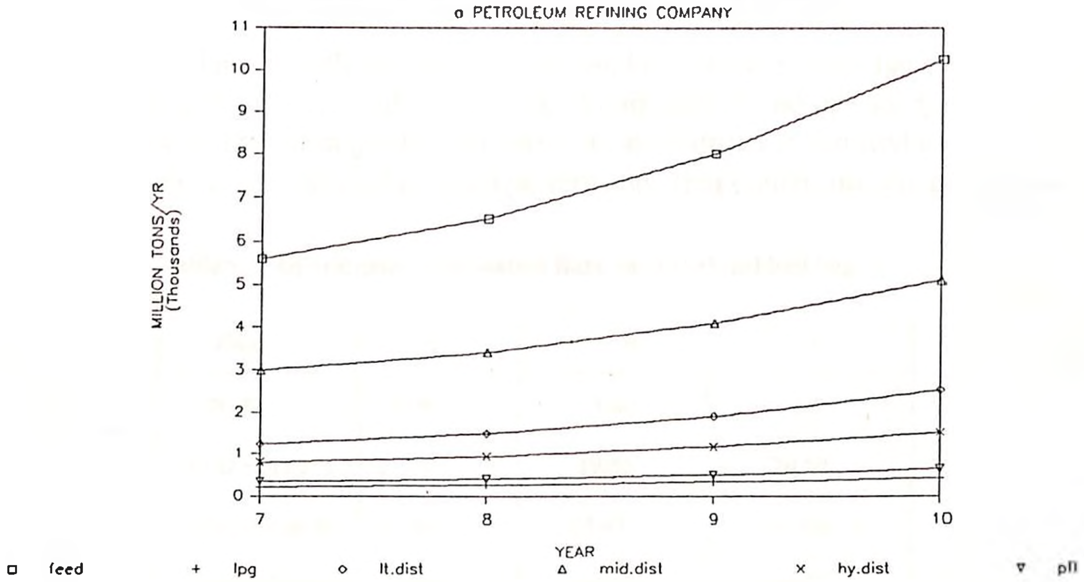
An estimated product demand pattern for the next five years is given in the table in the next page and fig 6.05 using lotus for the sake of simplicity .

Table 6.02 Production Planning Forcast

year	feed	lpg	light Dist	mid Dist	hy Dist	pfl	pfl (adj)	total (act)
7	5593.9658	218.4669	1235.963	2992.177	802.958	344.4036	344.4002	5593.969
8	6518.9375	259.5953	1498.059	3409.569	947.257	404.4609	404.4560	6518.942
9	8029.8091	325.9252	1916.366	4104.491	1181.001	502.0316	502.0246	8029.816
10	10264.4131	424.5064	2540.564	5124.901	1527.813	646.6374	646.6271	10264.42

year :	7	8	9	10
planned Shut down :	35	35	35	35
stream days:	330	330	330	300
T'put/stream day :	16951.41	19754.35	24332.75	31104.28
Hourly Rate	706.3088	823.0981	1013.864	1296.011

fig 6.05 Product forecast model for



Observations:

It may be observed that the demand for petroleum almost increases by 80% by tenth year and *in all likelyhood the unit may not be geared to process this much of feed stock within such a short time.* Decisions that may be arrived at from the forecasting model are

* whether the unit has the built-in capacity to meet the demand ?
* what are the additional facilities to meet the demand ?
* what will be the cost involvement etc.

For the sake of simplicity we shall examine the seventh year of operation in which the unit has to process 5593.96 thousand tons of feed stock.

LP model application:

Since the feed stocks to be processed are different and the yield patterns are also different for different feed stocks, only an **LP model** will be able to solve the problem. A typical LP model *(Ref 1, 4,5)* is given here to highlight this application .

There are three types of feed stocks A,B and C that have to be processed in the unit. The cost of feed stock , yield pattern and operating costs are given below. A premium grade feed stock C availability is limited to 2 million tons per year only. Potential product pattern and other constraints are given in **table 6.03.**

table 6.03 Operational Information Base for LP Model building

Feed	A	B	C
LPG %	5.00	3.60	3.50
Lt.Distillate %	21.00	19.85	20.50
M.Distillate %	58.00	55.45	57.00
Hy.Distillate %	12.00	14.40	14.00
PFL %	4.00	6.70	5.00
Cost of feed Rs / ton	3000	2800	2750
Operating Cost Rs / ton	500	690	710

Let xa ,xb and xc be the quantities of feed stock A ,B and C processed per annum in the unit .In this LP model, the objective function is to minimise the total cost . Since the ultimate product pattern will give constant cash inflow irrespective of the feed mix , it is only the total cost of the mix that has to be minimum so that the profits are maximised as the profits are determined by the following relationship.

$$\text{cash in flow} = p1*c1+p2*c2+p3*c3+p4*c4 \quad (1)$$

$$\text{cash out flow} = xa*(ca+oca+cp1*pfl1/100)+xb*(cb+ocb+cp2*pfl2/100)+xc*(cc+occ+cp3*pfl3/100) \quad (2)$$

$$\text{profit} = \text{cash in flow} - \text{cash outflow} \quad (3)$$

where p1,p2,p3 & p4 are products 1 to 4 respectively
c1,c2,c3 & c4 are cost of sale of products 1 to 4
xa,xb,xc are quantum of feed stock a,b & c processed / annum
ca,cb,cc are cost of feed stock in Rs/ton
oca,ocb,occ are operating cost in Rs/ton of a,b,c processed
cp1,cp2,cp3 cost of pfl in Rs/ton of pfl consumed.

Cost data:

c1=5000:c2=4500:c3=3800:c4=2600
oca = 500:ocb = 690: occ=710
cp1=1500:cp2=1800:cp3=1950
ca=2500:cb=2180:cc=2050

Applying the above relationship, operating profits to the enterprise due to processing of the feed stocks is given by *(Ref 20,24,26,27,34)*

Profit / ton of feed A :

*0.05*5000 + 0.21*4500+ 0.58*3800 + 0.12* 2600 - 0.04*1500 - 2500 - 500 = 651*

Profit / ton of feed B :

*0.036*5000 + 0.1985*4500 + 0.5545*3800 + 0.1440*2600 - 0.067*1800 - 2180 - 690 = 564.15*

Profit / ton of feed c :

$$0.035*5000 + 0.2050*4500 + 0.5700*3800 + 0.1400*2600 - 0.050*1950 - 2050 - 710 = 770.00$$

Profit maximisation function:

*maximise 651*xl + 564.15*xb + 770.0*xc*

Since the feed mix has direct effect on the product pattern and the overall profitability of operation, an LP model has been developed as shown in *table 6.04*.

table 6.04 Linear Programming Basis

	cost/t	X1	X2	X3
FEED	Rs/t	2500.00	2180.00	2050.00
LPG %	5000	5.00	3.60	3.50
Lt.Dist %	4500	21.00	19.85	20.50
Mid.Dist %	3800	58.00	55.45	57.00
Hy.Dist %	2600	12.00	14.40	14.00
PFL %		4.00	6.70	5.00
PFL cost/t		1500	1800	1950
PFL cost		60.00	120.60	97.50
Optg.Cost		500.00	690.00	710.00
Net Optg.Cost		560.00	810.60	807.50
Cash inflow		3711.00	3554.75	3627.50
less Cost of feed		1211.00	1374.75	1577.50
less net optg.cost		651.00	564.15	770.00
net profit/ton of feed processed		651.00	564.15	770.00

maximise 651*X1+564.15*X2+770*X3

ST	0.05*X1+0.036*X2+0.035*X3 >= 218467	(LPG)
	0.21*X1+0.1985*X2+0.205*X3 >= 1235963	(Lt.Dist.)
	0.58*X1+0.5545*X2+0.57*X3 >= 2992177	(Mid.Dist)
	0.12*X1+0.144*X2+0.14*X3 >= 802958	(Hy.Dist.)
	0.04*X1+0.067*X2+0.05*X4 <= 344404	(PFL)
	X3 <= 2000000	(Feed)

Above example is just to indicate how LP could be made use of in the production planning itself .The above sample may be solved by simplex method or LINDO program to get the optimum feed mix.

Production Scheduling and materials requirement planning:

From the forecasting models developed earlier, the next step to be followed is the development of targets on daily ,weekly, monthly , quarterly basis so that actual performance monitoring becomes easier. In this due consideration must be given for the planned shut down, unplanned shut down etc. *A typical program output is given in the next page.*

From this information, actual performance monitoring could be carried out using the operating data . A simple program could be developed to generate the required information for monitoring purposes. The data input for the program could be from the console or from the unit or from an input file. This information is **extremely important to achieve the production targets and also to operate the process efficiently .**

Typical monthwise production plan based on the stream days is given in *table 6.05,6.06 and 6.07* for the seventh year.

Production Planning Forecast

year	feed	lpg	light Dist	mid Dist	hy Dist	pfl	pfl (adj)
7	5593.9658	218.4669	1235.963	2992.177	802.958	344.40	344.4002
8	6518.9375	259.5953	1498.059	3409.569	947.257	404.46	404.4560
9	8029.8091	325.9252	1916.366	4104.491	1181.001	502.03	502.0246
10	10264.4131	424.5064	2540.564	5124.901	1527.813	646.63	646.6271

year :	7	8	9	10
planned Shut down :	35	35	35	35
stream days:	330	330	330	300
T'put/stream day :	16951	19754	24332	31104
Hourly Rate	706.3	823.1	1014.0	1296.0

table 6.05 Monthly Production target Setting (7th year)

month	SD Days (planned)	stream days	feed tpd	monthly rate
January	---	31	16965	525915
February	---	28	16965	475020
March	2	29	16965	491985
April	30	0	16965	0
May	3	28	16965	475020
June	---	30	16965	508950
July	---	31	16965	525915
August	---	31	16965	525915
September	---	30	16965	508950
October	---	31	16965	525915
November	---	30	16965	508950
December	---	31	16965	525915
total				5598450

table 6.06 Planned yield Pattern

product	%
LPG	3.9054
Lt.Dist	22.0946
M.Dist	53.4894
Hy.Dist	14.3540
PFL	6.1567
total	100.0000

table 6.07. Monthwise target for products.

month	LPG	Lt.Dist	M.Dist	Hy.Dist	PFL	total
January	20539.10	116198.7	281308.6	75489.83	32379.	525915.3
February	18551.45	104953.6	254085.2	68184.36	29245.	475020.3
March	19214.00	108702.0	263159.7	70619.52	30290.	491985.3
April		planned	annual	shut down		
May	18551.45	104953.6	254085.2	68184.36	29245.	475020.3
June	19876.55	112450.3	272234.1	73054.67	31334.	508950.3
July	20539.10	116198.7	281308.6	75489.83	32379.	525915.3
August	20539.10	116198.7	281308.6	75489.83	32379.	525915.3
September	19876.55	112450.3	272234.1	73054.67	31334.	508950.3
October	20539.10	116198.7	281308.6	75489.83	32379.	525915.3
November	19876.55	112450.3	272234.1	73054.67	31334.	508950.3
December	20539.10	116198.7	281308.6	75489.83	32379.	525915.3
total	218642.0	1236953.	2994576.	803601.4	344679	5598453

From the production planning schedule, and the targets developed by computer-aided programs as shown in *tables 6.05,6.06 and 6.07* , it is possible to monitor the performance of the complete production units by simulation models. Normal problems faced by the operating units are

a.Low capacity utilisation
b.Low efficiency
c.High overhead costs
d.Frequent equipment failure and shut-down of the units.
e.High production losses
f.High overtime costs
g.High energy consumption etc.

Using the daily operating data, it is possible to pin point the problem area **with certainty** for remedial action. For this purpose certain computer-aided models will be used. As mentioned earlier, the complete operating information required for monitoring purpose is entered in a data base file **master.dbf.**

This data base contains voluminuous information for different sections of the unit. Hence, each program is designed for a specific purpose and the required data will be retrieved from **master.dbf** and the decision model invoked for obtaining the required output (decision variable), that could be used to take appropriate decisions.

A typical section of **master.dbf** and fields used is shown in **table 6.08** to monitor the production performance of overall unit . A number of programs are used to indicate the application computer-aided production management system. Application of each program and the objectives are given below. This being a very voluminous exercise, certain important applications are shown in the output.

i.Production analysis:

The program just monitors the actual production against targeted production and identifies reasons for deviation in terms of emergency shut down , non-availability of feed, equipment failure , power failure etc..
Impact of feed mix on product pattern is identified by another model.
Another model is used to determine the impact of feed mix on yield pattern and losses.

table 6.08 Data base for production analysis

Field Name	*type*	*Length*	*Decimal*	
DATE	D	8	0	
UNIT_NAME	C	8	0	
FEED1	N	6	1	
FEED2	N	6	1	
FEED3	N	6	1	
DESFEED1	N	6	1	
DESFEED2	N	6	1	
DESFEED3	N	6	1	
PRODUCT1	N	6	1	
PRODUCT2	N	6	1	
PRODUCT3	N	6	1	
DESPROD1	N	6	1	
DESPROD2	N	6	1	
DESPROD3	N	6	1	
LOSSES	N	5	1	
DESLOSS	N	5	1	
POWER	N	7	1	
DESPOWER		N	7	1
FUEL	N	7	1	
DESFUEL	N	7	1	
STEAM	N	7	1	
DESSTEAM	N	7	1	
CHEMICALS	N	5	1	
DESCHEM	N	5	1	
POWER_COST	N	7	1	
DESPWRCST	N	7	1	
FUEL_COST		N	7	1
DESFUELCST	N	7	1	
STEAM_COST	N	7	1	
DESSTMCST	N	7	1	
CHEM_COST	N	7	1	
DESCHEMCST	N	7	1	
MAN_POWER	N	7	0	
DESMANPWR	N	7	0	
M_PWR_COST	N	7	1	
FEED1_COST	N	7	1	
FEED2_COST	N	7	1	
FEED3_COST	N	7	1	
PROD1_COST	N	7	1	

Field Name	*type*	*Length*	*Decimal*
PROD2_COST	N	7	1
PROD3_COST	N	7	1
FIXED_CST	N	9	1
GROSS_IN	N	9	1
CAP_UTIL	N	6	2
SD_HRS	N	5	1
PRODN_LOSS	N	9	1
*** Total **		307	

Table 6.09. CAPACITY UTILISATION INFORMATION
(ABC Petroleum Corporation Ltd)

month	unit	actual t'put	planned t'put	% cap utilizn	hours lost	prodn loss
01/31/96	ul	500000	525915	95.1	0.0	0.0
02/28/96	ul	465000	475020	97.9	0.0	0.0
03/31/97	ul	435900	491985	88.6	0.0	0.0
04/30/96	ul	0	0	0	0.0	0.0
05/31/96	ul	413250	475020	87.0	0.0	0.0
06/30/96	ul	500000	508950	98.2	0.0	0.0
07/31/96	ul	513255	525915	97.6	0.0	0.0
08/31/96	ul	514567	525915	97.8	0.0	0.0
09/30/96	ul	492347	508950	96.7	0.0	0.0
10/31/96	ul	512355	525915	97.4	0.0	0.0
11/30/96	ul	499875	508950	98.2	0.0	0.0
12/31/96	ul	512550	525915	97.5	0.0	0.0
* Total *		5359099	5598450		0.0	0.0

The above **table 6.09** is the output created by the ***capacity utilisation program*** which actually calculates the capacity utilisation of the unit from the entered data . Hrs lost column gives the unit shut down time in hours due to equipment failure, feed failure, power failure, high inventory etc.

Reasons for this could also be identified using the **lost_hrs** data and the **prodn_loss code** . The program has the capability to determine the production loss in tons . From this, the executive may determine the course of action for reducing the loss by appropriate actions. In the absence of such analysis, it is very difficult to monitor the unit performance. Since the data is available at the beginning of every month it is possible to take the right action at right time and avert failure.

Same data base may be used for daily production performance monitoring and control also. The pre-requisite for such a system is the accurate day to day material balace which is possible only with automatic data tranfer and retrieval system .

Table 6.10 PRODUCTION LOSS ANALYSIS FROM MASTER DATA BASE INFORMATION

month	unit	prod1	prod2	prod3	prod4	design pfl	actual pfl
01/31/96	u1	19123	109500	266500	70790	32380	34087
02/28/96	u1	17001	101890	247760	66180	29245	32169
03/31/97	u1	16825	94999	232000	62140	30290	29936
04/30/96	u1	0	0	0	0	0	0
05/31/96	u1	15712	90005	220007	59171	29245	28355
06/30/96	u1	19500	110395	267200	71595	31334	31310
07/31/96	u1	20000	112800	274512	73478	32380	32465
08/31/96	u1	20049	113609	274902	73617	32380	32390
09/30/96	u1	19109	108281	263118	70238	31334	31601
10/31/96	u1	19991	113007	273699	73400	32380	32258
11/30/96	u1	19498	110375	267223	71642	31334	31137
12/31/96	u1	20000	113007	274005	73512	32380	32026
Total		206808	1177868	2860926	765763	344682	347734

Table 6.10 given above is the output of **loss analysis program.** This estimates the actual plant fuel and loss from the reconciled material balance . PFL is given by the expression

losses in tons = *mass flow of input streams* - *mass flow of output streams*

The program automatically creates an input file which will be used by the modelling program to analyse the losses as a funtion of capacity utilisation.User will enter the name of a file with an extension *. in to be retrieved by the program. Since there are some strings, in the input file, the file will be modified to meet the stipulated input format. In the example, the file name chosen is **file4.in.** *This will be used for creating a capacity utilisation vs losses model.*

Capacity Utilisation VS Plant fuel and Loss Model

ABC PETROLEUM CORPORATION
No of data sets used in the model : 11
Variables used : cap_util pfl

a.Input Details of the model

file name : **b:\file4**
base value for X variable : 0

b. PFL data

X values CAP_UTILZN %	PFL IN TONS / M
95.07	34087.0000
97.89	32169.0000
88.60	29936.0000
87.00	28355.0000
98.24	31310.0000
97.59	32465.0000
97.84	32390.0000
96.74	31601.0000
97.42	32258.0000
98.22	31137.0000
97.46	32026.0000

c. PROGRAM OUTPUT

i.Linear Model

cap %	X1	ACTUAL	simulated
95.07	95.0700	34087.0000	31457.5078
97.89	97.8900	32169.0000	32219.0977
88.60	88.6000	29936.0000	29710.1699
87.00	87.0000	28355.0000	29278.0625
98.24	98.2400	31310.0000	32313.6211
97.59	97.5900	32465.0000	32138.0762
97.84	97.8400	32390.0000	32205.5938
96.74	96.7400	31601.0000	31908.5195
97.42	97.4200	32258.0000	32092.1660
98.22	98.2200	31137.0000	32308.2207
97.46	97.4600	32026.0000	32102.9688

STANDARD ERROR OF ESTIMATE IS : 975.5033

ii.Exponential Model

Cap %	X1	ACTUAL pfl	simulated pfl
95.07	95.0700	34087.0000	31418.6855
97.89	97.8900	32169.0000	32219.1543
88.60	88.6000	29936.0000	29656.5059
87.00	87.0000	28355.0000	29236.1895
98.24	98.2400	31310.0000	32319.9141
97.59	97.5900	32465.0000	32133.0352
97.84	97.8400	32390.0000	32204.7832
96.74	96.7400	31601.0000	31890.2871
97.42	97.4200	32258.0000	32084.3398
98.22	98.2200	31137.0000	32314.1484

STANDARD ERROR OF ESTIMATE : 983.7709

iii.Non-Linear Model

cap %	X1	ACTUAL pfl	simulated pfl
95.07	95.0700	34087.0000	32519.1445
97.89	97.8900	32169.0000	32003.5273
88.60	88.6000	29936.0000	30049.1465
87.00	87.0000	28355.0000	28653.5957
98.24	98.2400	31310.0000	31872.1035
97.59	97.5900	32465.0000	32104.3281
97.84	97.8400	32390.0000	32021.0879
96.74	96.7400	31601.0000	32330.5176
97.42	97.4200	32258.0000	32156.5918
98.22	98.2200	31137.0000	31880.0137
97.46	97.4600	32026.0000	32144.6094
97.46	97.4600	32026.0000	32095.7910

STANDARD ERROR OF ESTIMATE : 623.6456

D.Polynomial Model

Cap %	X1	ACTUAL pfl	simulated pfl
95.07	95.0700	34087.0000	33616.0508
97.89	97.8900	32169.0000	31784.0488
88.60	88.6000	29936.0000	30325.3809
87.00	87.0000	28355.0000	28032.9004
98.24	98.2400	31310.0000	31408.3711
97.59	97.5900	32465.0000	32079.5391
97.84	97.8400	32390.0000	31834.9941
96.74	96.7400	31601.0000	32785.1602
97.42	97.4200	32258.0000	32236.1719
98.22	98.2200	31137.0000	31430.7363
97.46	97.4600	32026.0000	32200.0176

STANDARD ERROR OF ESTIMATE : 487.1913

d. SIMULATED OUTPUT FOR NEW CONDITIONS

i.Linear Model

cap%	Z1	simulated pfl
85.0	85.0000	28737.9277
90.0	90.0000	30088.2656
95.0	95.0000	31438.6035
97.5	97.5000	32113.7715
100.0	100.0000	32788.9414

ii.Exponential Model

cap%	Z1	simulated pfl
85.0	85.0000	28719.1621
90.0	90.0000	30029.2363
95.0	95.0000	31399.0723
97.5	97.5000	32107.2480
100.0	100.0000	32831.3945

iii.Non-Linear Model

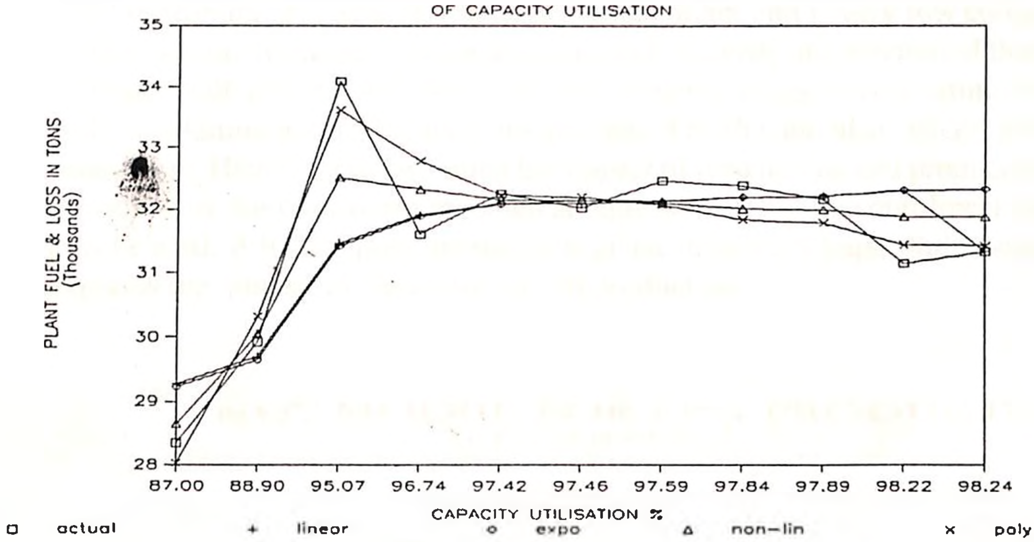
Cap %	Z1	simulated pfl
85.0	85.0000	26471.5723
90.0	90.0000	31014.9980
95.0	95.0000	32519.6484
97.5	97.5000	32132.4336
100.0	100.0000	30985.5254

iv.Polynomial Model

cap %	Z1	simulated pfl
85.0	85.0000	24410.3438
90.0	90.0000	31870.1641
95.0	95.0000	33635.0938
97.5	97.5000	32163.4316
100.0	100.0000	29005.7871

Fig 6.06 given below explains how the plant fuel and loss varies with capacity utilisation of the plant. From loss control point of view, the PFL may be estimated at any particular capacity utilisation and compared with actual for corrective action.

fig 6.06 MODEL FOR PFL SIMULATION AS F



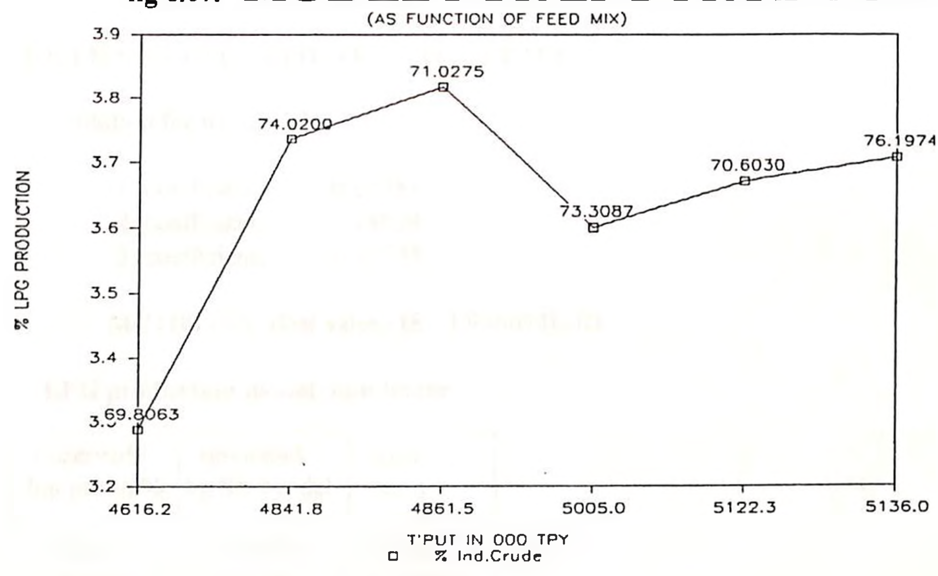
It may be noted that as the capacity utilisation increases, pfl starts coming down . This is because of the higher efficiency of equipments at full load or very near full load.

These models may be different from the base case as aging is also one of the factors that affects the efficiency of the system and hence the pfl . A comparison with base case or design case, may be very helpful in taking ' equipment maintenance and / or replacement decisions '. In energy intensive industries , this is a very important parameter that has to be given due consideration . This approach has been found to be very useful and effective in controlling energy costs and losses in many industries.

Feed mix effect on product pattern:

Since most of the units are processing more than one feed stock, and the down stream units operate at varying degrees of severity, the product pattern of such parametric variations tend to affect the yield pattern and the *production manager would like to maximise* the yield of high value products than low value products. This is the case with refining industry also. As has been seen earlier, LPG fetches high returns and hence the objective is to determine the feed mix that will yield maximum LPG. Straight run LPG from the main unit is very low compared to that coming from the fluid catalytic cracker. Severity of operation of this unit increases both LPG and distillates, but this increases losses and operating cost as well. In addition to this, the feed mix processed by the unit also affects the LPG production. Hence for determining the impact of feed mix on LPG production, as a function of feed composition, a linear regression model or a non-linear model may be used. A typical program output is given in the next page while the **fig 6.07** explains the impact of feed mix on LPG production.

fig 6.07. MODEL FOR LPG PRODUCTI



It may be noted that indigeneous feed stock gave more LPG production than others. Increase in crude capacity, tends to increase LPG yield because of high feed stock availability for the cracker. Sensitivity analysis may be carried out to determine the impact of capacity and % ind. feed on LPG yield. This is given in **fig 6.08**.

a.Title: LPG production model

b.No of data sets used in the model : 6

c.Independant variables used in the model : 2

Variables used in the model are ......

variable 1 is t'put
variable 2 is ind_%
variable 3 is lpg%

Data input for LPG production model

t'put in '000	ind_% by wt	lpg% by wt
5136.0	76.1974	3.7077
4861.5	71.0275	3.8182
5122.3	70.6030	3.6706
4841.8	74.0200	3.7352
5005.0	73.3087	3.6006
4616.2	69.8063	3.2880

SCIENTIFIC MODEL OUTPUT

solution for the model ....

1 coefficient: 0.65781
2 coefficient: 0.28824
3 coefficient: -5.53758

MUTIPLIER (last value) IS 3.936054E-03

LPG production model non linear

observed lpg prodn %	simulated by Sci.Model	error term
3.7077	3.78772	-0.08002
3.8182	3.58006	0.23814
3.6706	3.69887	-0.02827
3.7352	3.61324	0.12196
3.6006	3.68263	-0.08203
3.2880	3.44293	-0.15493

Standard Error of the estimate = 0.14800

LPG production model (linear)

solution is ....

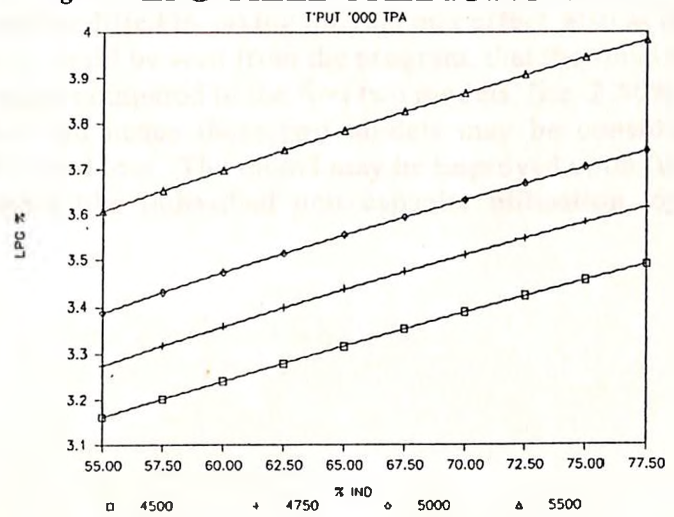
1	coefficient:	0.00045
2	coefficient:	0.01396
3	coefficient:	0.38462

Last coefficient in the row
is a constant

observed lpg prodn %	simulated lpg prodn %	error term
3.70770	3.78180	-0.07410
3.81820	3.58491	0.23329
3.67060	3.69746	-0.02686
3.73520	3.61775	0.11745
3.60060	3.68195	-0.08135
3.28800	3.45643	-0.16843

Standard Error of the estimate = 0.14793

Fig 6.08 LPG YIELD PREDICTION BY EL



Plant fuel and loss monitoring:

Another key area of control is the plant operating cost of which plant fuel and loss constitute nearly 75 % of the total operating cost. Plant fuel and loss is variable and is determined by the individual capacity utilisation level of each unit , severity of operation and the equipment efficiency . Hence, the operations manager may be able to monitor the plant fuel loss using a suitable model and compare it with actual for necessary action. A typical model output is given in the next page that may be used to predict the plant fuel loss as a function of capacity utilisation. In this model all the units are taken to operate at the matching capacity and other parameters are assumed to be constant. This ultimately narrows down to a capacity utilisation vs pfl mode l. Program is based on these parameters for the sake of simplicity.

Interpretation :

In the first two models, an attempt was made to correlate the plant fuel and loss to the throughput processed, which is a logical step .From the output of these models, it is noticed that the standard error level is about 7.00 % which is high . Hence it may be interpreted there are other factors that contribute to plant fuel and loss. Feed mix is one of the factors that affects the fuel consumption. High sulphur feeds require additional treatment, thereby consuming more energy. Similarly, operating severity is also yet another factor that has to be considered.

This model was modified by taking the fuel mix effect also as shown in three variable model. It could be seen from the program, that the standard error level is just half the value compared to the first two models. (i.e. 2.50%) . This is a reasonable value and hence these two models may be considered for prediction of plant fuel and loss. The model may be improved upon further by taking other parameters like individual unit capacity utilisation, operating severity etc.

ABC Petroleum Corporation Ltd

a.Input Details of the model

file name : b:\pfl.out
base value for X variable : 0

X values t'put	*Y values pfl %*
4616.2	5.9000
4841.8	6.2000
4861.5	7.1000
5005.0	5.7000
5122.3	6.0000
5136.0	6.2000

b. P R O G R A M O U T P U T

Plant Fuel and Loss Model for a Refinery

A.Linear Model

t'put	*X1*	*actual pfl %*	*simulated pfl %*
4616.2	4616.2002	5.9000	6.2530
4841.8	4841.7998	6.2000	6.2030
4861.5	4861.5000	7.1000	6.1986
5005.0	5005.0000	5.7000	6.1668
5122.3	5122.2998	6.0000	6.1408
5136.0	5136.0000	6.2000	6.1378

STANDARD ERROR OF ESTIMATE IS : 0.4432

B.Exponential Model

t'put	*X1*	*actual pfl %*	*simulated pfl %*
4616.2	4616.2002	5.9000	6.2309
4841.8	4841.7998	6.2000	6.1858
4861.5	4861.5000	7.1000	6.1819
5005.0	5005.0000	5.7000	6.1533
5122.3	5122.2998	6.0000	6.1301
5136.0	5136.0000	6.2000	6.1274

STANDARD ERROR OF ESTIMATE : 0.4435

C.Non-Linear Model

t'put	*X1*	*actual pfl %*	*simulated pfl %*
4616.2	4616.2002	5.9000	5.9680
4841.8	4841.7998	6.2000	6.4270
4861.5	4861.5000	7.1000	6.4332
5005.0	5005.0000	5.7000	6.3145
5122.3	5122.2998	6.0000	6.0031
5136.0	5136.0000	6.2000	5.9541

STANDARD ERROR OF ESTIMATE : 0.3956

D.Polynomial Model

t'put	*X1*	*actual pfl %*	*simulated pfl %*
4616.2	4616.2002	5.9000	6.1128
4841.8	4841.7998	6.2000	6.2967
4861.5	4861.5000	7.1000	6.3114
5005.0	5005.0000	5.7000	6.3072
5122.3	5122.2998	6.0000	6.0601
5136.0	5136.0000	6.2000	6.0112

STANDARD ERROR OF ESTIMATE : 0.4252

Three Variable Plant fuel & loss model

b.No of data sets used in the model : 6
c.Independant variables used in the model : 2

Variables used in the model are ......

variable 1 is **t'put**
variable 2 is **ind_%**
variable 3 is **pfl%**

data set 1

variable 1 5136
variable 2 76.1974
variable 3 6.108

data set 2

variable 1 4861.5
variable 2 71.0275
variable 3 5.99

data set 3

variable 1 5122.3
variable 2 70.603
variable 3 5.97

data set 4

variable 1 4841.8
variable 2 74.02
variable 3 6.2805

data set 5

variable 1 5005
variable 2 73.3087
variable 3 5.71

data set 6

variable 1 4616.2
variable 2 69.8063
variable 3 5.88

SCIENTIFIC MODEL OUTPUT

solution for the model ....

1 coefficient:	-0.18731
2 coefficient:	0.51671
3 coefficient:	1.16917

MUTIPLIER 3.219307

Three Variable Plant fuel & loss model

observed pfl %	*simulated by Sci.Model*	*error term*
6.1080	6.09714	0.01086
5.9900	5.94057	0.04943
5.9700	5.86451	0.10549
6.2800	6.07322	0.20728
5.7100	6.00558	-0.29558
5.8800	5.94495	-0.06495

Standard Error of the estimate = 0.17219

Three Variable Plant fuel & loss model

solution is ....

1 coefficient: -0.00024
2 coefficient: 0.04345
3 coefficient: 4.01745

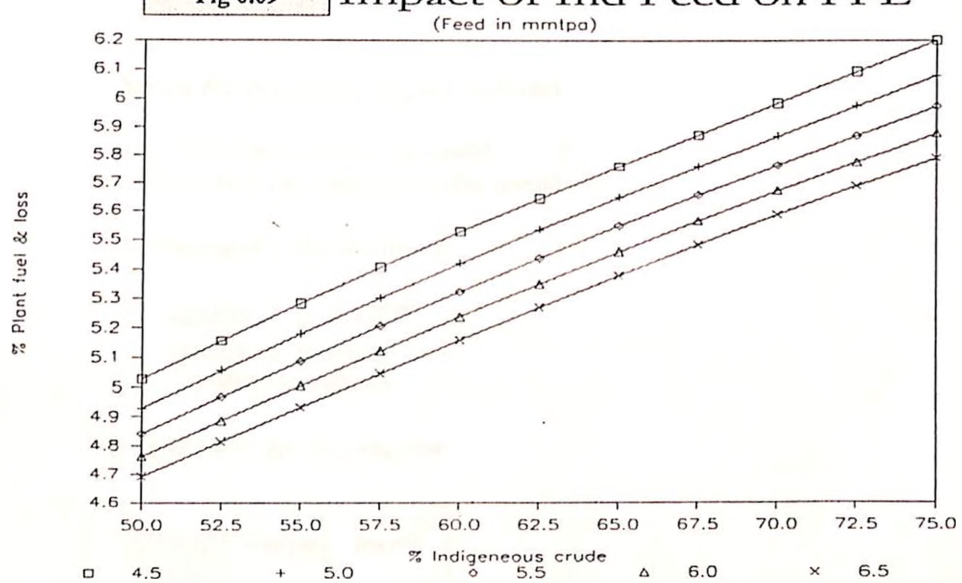
observed pfl %	simulated pfl %	error term
6.10800	6.10158	0.00642
5.99000	5.94251	0.04749
5.97000	5.86177	0.10823
6.28050	6.07724	0.20326
5.71000	6.00736	-0.29736
5.88000	5.94804	-0.06804

Standard Error of the estimate = 0.17226

Impact of feed rate and % Ind feed on Plant fuel and loss:

Using the non-linear, three variable model a sensitivity analysis has been carried out to identify the impact of feed rate (in '000 mt / y) and % indigenous crude on plant fuel and loss (weight % on feed). The information has been given below in fig 6.09.

Fig 6.09 Impact of Ind Feed on PFL



It may be noted that for the same feed rate , % plant fuel and losses increases with % ind feed. This means, some additional energy is being consumed in processes or the unit is not designed to process this quantum of ind feed due to process constraints resulting in excess flaring and other losses . These type of information could be generated with the help of models easily due to systematic data processing .

Impact of Shut Down on Losses:

A process plant gets shut down due to a number of reasons such as

* Power failure
* Equipment failure
* Feed non availability
* Steam failure

* Instrument failure
* Air failure
* Major fire and/or explosions etc

Each shut down, affects the plant fuel and loss figure and it may be generally stated that loss is proportional to the frequency of shut down. Hence, a production manager has to assign certain quantity of loss due to shut down. For arriving at this, models may be used effectively. Following models explain the impact of shut down on losses.

Model for shut down impact on losses

b.No of data sets used in the model : 8
c.Independant variables used in the model : 2

Variables used in the model are ......

variable 1 is SDTOT
variable 2 is mmtpa
variable 3 is loss%

d. Input Data for the program

SDTOT days	*mmtpa*	*loss%*
20.80	4.116	0.606
54.40	4.111	0.333
33.00	4.761	0.652
36.00	4.616	0.458
9.90	5.006	0.778
32.60	4.842	0.551
4.20	5.122	0.774
31.80	4.861	0.651

SCIENTIFIC MODEL OUTPUT

solution for the model ....

1 coefficient: -0.17426
2 coefficient: 1.43506
3 coefficient: -2.21308

MUTIPLIER (last value) IS .1093635

Effect of shut down days on losses

observed loss %	simulated by Sci.Model	error term
.606	0.49090	0.11510
.333	0.41445	-0.08145
.652	0.55820	0.09380
.458	0.52593	-0.06793
.778	0.73991	0.03809
.551	0.57309	-0.02209
.774	0.88787	-0.11387
.651	0.57882	0.07218

Standard Error of the model = 0.08735

Multivariable linear model:

Effect of shut down days on PFL

solution is ....

1 coefficient: -0.00702
2 coefficient: 0.11379
3 coefficient: 0.26320

Last coefficient in the row
is a constant

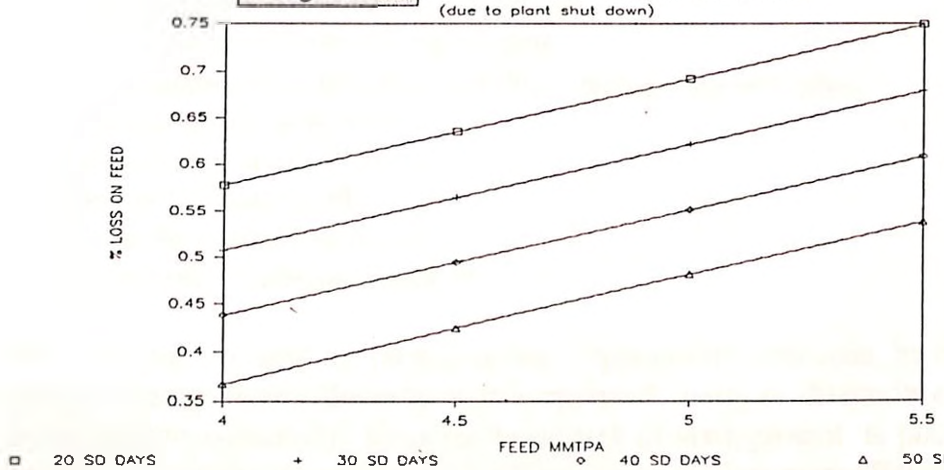
observed loss %	*simulated by model*	*error term*
0.60600	0.58564	0.02036
0.33300	0.34936	-0.01636
0.65200	0.57345	0.07855
0.45800	0.53590	-0.07790
0.77800	0.76337	0.01463
0.55100	0.58547	-0.03447
0.77400	0.81656	-0.04256
0.65100	0.59324	0.05776

Standard Error of linear model = 0.05274

Shut Down Analysis:

While the above models indicate the impact of shut down days quantitatively on the losses, figure 6.10 given below explains a lot more on the shut down losses.

Fig. 6.10 . Process Loss Model



It may be noted from the above figure, that for the same throughput level losses tend to go down with more shut down days. This means, that the losses are low due to better maintenance and better equipment efficiency. One more point that has to be considered in the case is planned shut down and unplanned shut down. More unplanned shut downs and frequency tend to show up higher losses, while longer planned shut downs reduce losses due to the reasons given above. Hence, the decision maker may plan for shut down effect on losses during the planning stage itself.

It may be noted that all the models given in this thesis are used for taking managerial decisions and with the help of these, it is possible to monitor the plant performance effectively, using the data. This is far superior to the conventional method of *ad hoc* monitoring.

Other area of interest for the production / planning manager is to determine in advance the specific consumption of fuel, steam,power,energy, chemicals , catalysts etc which may be used for monitoring the operating cost and profitablity of the organisation. Similar methods mentioned above are used for each specific case and some of them are covered in other chapters.

Conclusion:

This chapter explained how computer-aided production planning and monitoring system could be implemented using EORT and other regression models. These models covered activities like

1.Development of production forecasts
2.Conversion of forecasts into targets.
3.Conversion of targets into monthly / daily production plans
4.Identification of feed mix
5.Development of LP model
6.Impact of feed on PFL
7.Shut down analysis model
8.Profit maximisation model etc

These outputs are used for taking various Operational Decisions by different groups of executives . Because of this approach, unity of direction could be accomplished effectively. Since the basic task of management is planning in advance , this approach is capable of utilising the resources more effectively and scientifically and as such improves the productivity of the organisation.

Computer-aided Utility Management

Models may be effectively used in the area of Utility Management in process Industries which consume substantial quantity of steam and power. In view of the dynamic plant operating conditions and capacity utilisation of the main unit and down-stream units, the manager has to know

1. Whether the consumption level of utilities is normal or not ?
2. What should be the current consumption under the present conditions ?
3. What is the actual consumption ?
4. What is the deviation ?
5. Whether it is optimal ?
6. How should the combined heat and power cycle be modified ? etc.

In a nut shell the Operations Manager has to determine whether or not his system is working effectively , by using *'flexi-targeting'* methodology . EORT models may be used as an effective tool to develop these targets under dynamic conditions . *(8, 30,34,59)* .

Computer aided Utility management presented in this section (*21*) covers the following real life models for the *case study of the typical refinery given in chapter 6.*

* *Steam and Power consumption models*
* *Optimisation of Combined Heat Power Cycle*
* *Generic models*
* *Boiler efficiency model*
* *Turbine performance model*
* *Pressure Correlation Index model*
* *Steam leaks monitoring model*
* *Cooling water consumption model*
* *Specific consumption model*
* *Trouble shooting corrosion in CW systems by modelling*
* *Scale prediction model*

Output of the model parameters are directly used to set the *'flexi target'* at any point of time for monitoring purpose and diagnose the problems by systematic analysis.

Utilities play a major role in controlling the Operating costs of process and power industries. Hence adequate attention must be paid to utility management to control this cost and improve profits to the organization.

Utilities include steam, cooling water, demineralized water, electric power, refrigeration, compressed air , instrument air , effluent treatment etc. Their effect on the cost of product will depend on the process involved. Utility costing is complex, as one utility requires other utilities for their own generation.

The main objective of Utility Management is to decide

**What is the utility requirement for the existing configuration ?*
**Whether the current level of consumption is within norms ?*
**What are the reasons for higher / lower consumption and which section / equipment is responsible ?*
**What impact does this make on cost of operation ?*
**How can the utility cost be reduced within the constraints ?*
**What alternatives could be thought of to improve the productivity ?*
**What is the impact of technology mix on utility cost ?*
**Whether to adopt a modern technology or retrofit the existing system etc.*

1.Monitoring Steam and Power Consumption:

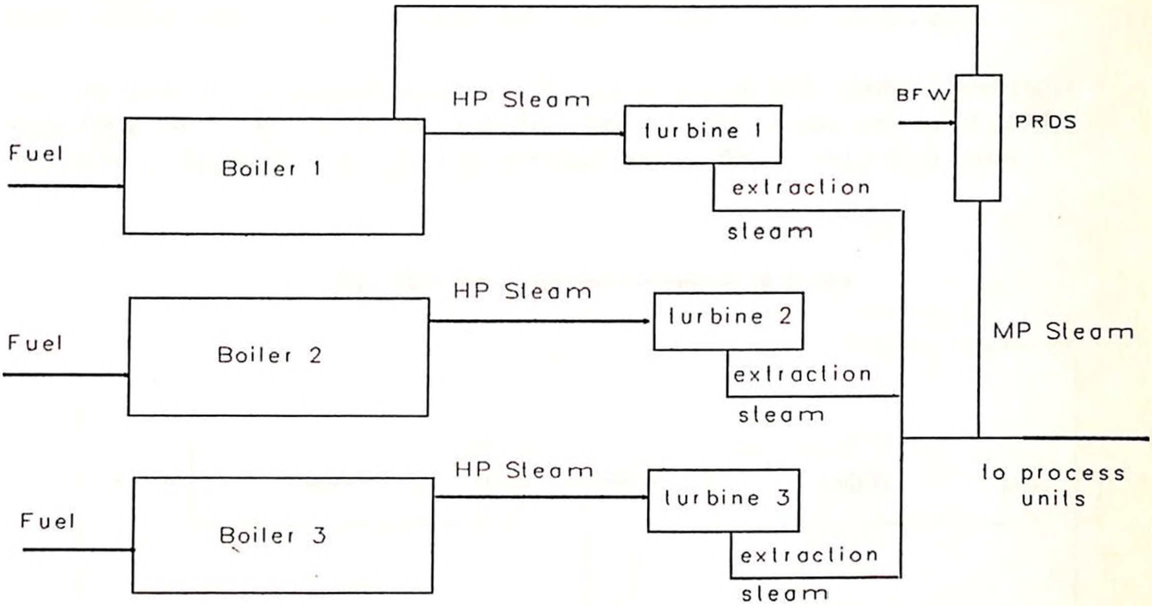
Steam is consumed in process and power industries for driving compressors, turbines and for heating process fluids ,creating vacuum by ejectors etc. Steam pressure depends on the process configuration , type of equipments used and the choice of Combihed Heat Power cycle selected. In normal practice, cost of steam alone constitutes about 60 to 70 % of the total utility cost.

Steam Consumption could be monitored by an overall steam balance of the set up on a day to day basis which include the quantity of steam generated and steam consumed at various sections.The difference between the two denotes steam loss which should be minimum.

Steam consumption is dynamic in nature. Steam demand is a function of load factor of individual unit , efficiency of various rotating equipments deployed, heat recovery level , feed stock quality, operating severity etc. of each unit / section .
Under these dynamic conditions, computer-based models could be used effectively to monitor the steam consumption of individual unit, monitor overall steam demand and identify deviations and problem areas for remedial action. A typical utility flow diagram for the refinery units is given in **fig 7.01.**

The total load of steam and power required by the refinery under consideration is determined by the model which is used as the target value, against which actual consumption levels are compared for remedial action .

fig 7.01 . Typical Steam - Power Flow diagram.



no of boilers 3 (100 t/hr , 40 kg/cm2)
no of turbines 3 (10 mw/hr @ full load)

Steam Generation Capacity of boilers 1,2 & 3 : 100 t/hr
Power Generation of eact turbine :10000 kw /hr @ total condensing mode.

From the steam-flow diagram it may be observed that the performance of the overall system is governed by a number of process parameters related to the downstream units such as the *capacity utilisation, efficiency of steam drives deployed*, *efficiency of heat transmission system*, *power demand etc and also that of total boiler-turbine system efficiency* . The inter relationship between these parameters is so complex that optimal solution cannot be arrived at by simple techniques whereas a multi variable model may handle this dynamic problem more easily.

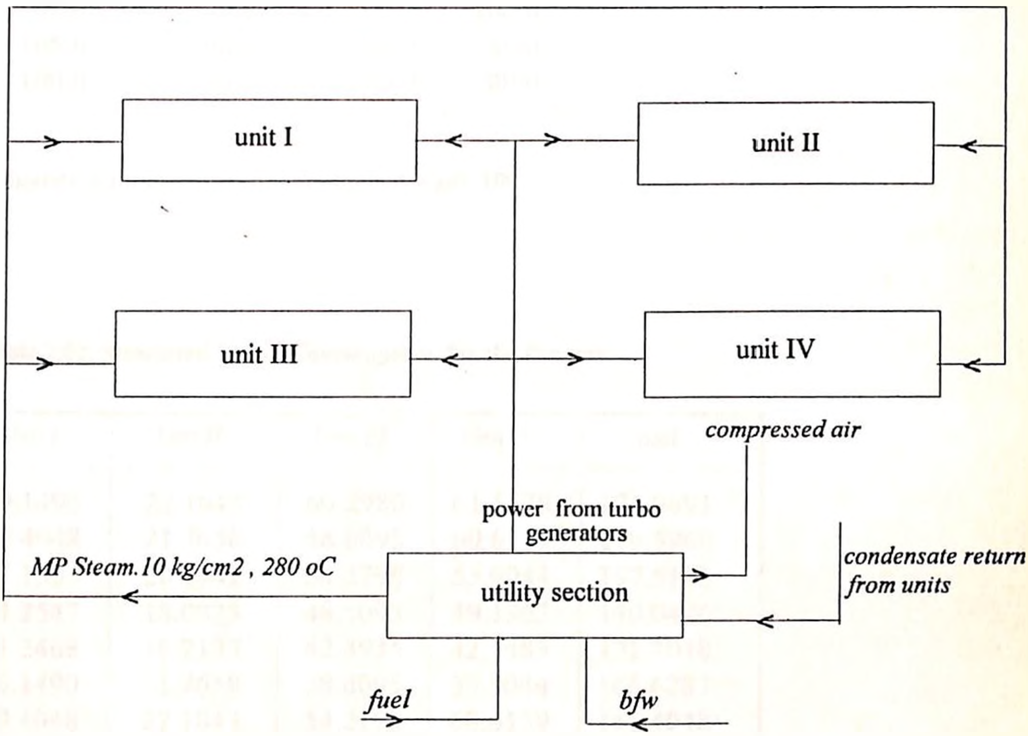
The specific consumption of fuel of the power boiler system is a *function of steam and power load*. The efficiency will be the highest at a certain load factor for each boiler / turbine combination. Steam and Power load in turn depends on the *capacity utilisation of down stream units and their efficiency* independantly.

From Steam and Power consumption point of view, total steam demand is the sum of individual subsystem demand including losses. Similarly total power demand is the sum of the independant power demand plus losses. Using the Power and Steam demand models , it is possible to estimate with fair degree of accuracy , what should be the total demand if the targeted capacity utilisation and production levels are to be achieved .

For meeting these targets, *optimal combination of heat-power cycle* may be arrived at . This could be compared with actual consumption of steam and power of the existing system and remedial measures could be taken in case of any abnormality.

Fig 7.02 given below describes the distribution of power and steam to four units which form the subsystem of the industry. Any number of subsystems could be considered in the models though this particular case refers to only four units .

Fig 7.02. Steam , Power and Compressed Air System



As could be seen from the above figure , Utility Section forms the *Cost Centre* and the individual unit demands for steam and power are dependant on each unit capacity utilisation or level of activity.

From utility management point of view, the total demand could be controlled by improving individual unit performance and this could be achieved by using the performance models for each unit. Using the capacity utilisation level of each unit , the total demand for each utility could be established and compared with actual level of consumption for necessary action. (**Refer tables 7.01,7.02 & 7.03**)

Table 7.0 1. Capacity Utilisation Data

Unit I	*Unit II*	*Unit III*	*Unit IV*
105.0	105.0	105.0	105.0
100.0	100.0	100.0	100.0
90.0	90.0	90.0	90.0
80.0	80.0	80.0	80.0
70.0	70.0	70.0	70.0
105.0	100.0	100.0	90.0
100.0	105.0	90.0	100.0
90.0	90.0	90.0	100.0
105.0	90.0	100.0	80.0
100.0	90.0	70.0	80.0

Capacity Utilisation % = (actual / design)*100

Table 7.02. Simulated Steam Consumption for the Process

Unit I	*Unit II*	*Unit III*	*Unit IV*	*Total*
30.1490	22.1043	60.2980	61.5178	174.0691
29.4048	21.7658	58.8095	60.6159	170.5960
27.1399	20.1942	54.2798	55.9044	157.5183
24.2547	18.0823	48.5093	49.1963	140.0426
21.2468	16.2133	42.4935	42.7483	122.7018
30.1490	21.7658	58.8095	55.9044	166.6287
29.4048	22.1043	54.2798	60.6159	166.4048
27.1399	20.1942	54.2798	60.6159	162.2298
30.1490	20.1942	58.8095	49.1963	158.3490
29.4048	20.1942	42.4935	49.1963	141.2888

*** Steam Consumption in t/hr.**

Note : Total steam demand for the dynamic condition of the process is determined by the sum of individual demand, determined by the model for each unit . This is applied for 'flexi-target' setting of the total system. (*ref 21,24*)

Table 7.03. Simulated Power Consumption for the Process

Unit I	*Unit II*	*Unit III*	*Unit IV*	*Total*
2814.58	2008.28	5024.81	6683.87	16531.55
2743.86	1955.07	4865.32	6481.01	16045.27
2564.47	1831.51	4481.06	6005.92	14882.97
2334.50	1685.11	4009.74	5458.90	13488.25
2053.93	1515.88	3451.36	4864.59	11885.77
2814.58	1955.07	4865.32	6005.92	15640.90
2743.86	2008.28	4481.06	6481.01	15714.22
2564.47	1831.51	4481.06	6481.01	15358.06
2814.58	1831.51	4865.32	5458.90	14970.31
2743.86	1831.51	3451.36	5458.90	13485.63

*** Power in kw / h**

From the tables it could be seen that the *load factor of the process units vary between 70 to 105 percent* resulting in steam demand between 122 to 174 tons / hr while the *power demand varies between 11886 to 16531 kw / hr. This demand includes the normal losses and process variations and will have to be met with by optimal operation of the boiler and turbine combinations.*

Generic Models:

While the above models could be developed from individual unit data and synthesised to arrive at utility consumption figures, it is also possible to develop generic models for faster decisions to determine the steam and power demand of the total system.

Using the same data, multi variable non linear models could be developed as given below. These models are capable of estimating the steam and power demand with fair degree of accuracy for the total system .

$$\text{a.PWR} = 367.0295 * C1^{.18295} * C2^{.01980} * C3^{.25972} * C4^{.35833}$$

$$\text{b.STM} = 2.809573 * C1^{.21262} * C2^{.0345} * C3^{.2804} * C4^{1.03303}$$

where

PWR = power in kw/h
STM= MP steam in tons/hr
C1,C2,C3 and C4 are load factor of units I ,II ,III and IV in %.

From operational point of view , these models are quite useful as they predict the abnormalities in utility consumption more precisely and exact location could be pin pointed from the individual utility consumption data .

Combined Heat - Power Cycle Optimisation:

As explained earlier, the ultimate objective of using the utility models is to optimise the combined heat power cycle to minimise the utility cost.

For the process system as given in fig 7.02 , following operational modes are available for meeting the utility demand .

a.One boiler and turbine at 100% load , Second boiler @ 100% load and 2nd turbine in extraction mode to meet the balance power and 3rd boiler to meet the balance steam.

b.All the three boilers and turbines in extraction mode.

c.One boiler and turbine at 100% load , and the other two boilers and turbines in extraction mode.

This concept of *Combined Heat - Power Optimisation* is very critical in utility cost control . Each one of the operation mode as given above has got a direct impact on the *combined efficiency of the total utility system* as high load factor increases the boiler efficiency and reduces fuel consumption cost. This could again be optimised by multi-variable dynamic models.

Any variation in plant load , steam leaks, drop in efficiency of rotating equipments like centrifugal compressors , turbine pumps etc will affect the Heat - Power cycle of the utility section and ultimately the cost of utility and operating costs. A typical Combined Heat Power Cycle model for the steam turbines and the methodology for optimising the utility cost is given below. (Working Details and the individual data are not given.)

Heat Power Cycle Model for Steam Turbine:

This has been arrived at using the pass-out steam flow , steam inlet flow and the power generation data at terminals.

BLR LOAD = 0.02737 * PWR + 1.85148 * STM - 185.59731

Standard Error : 1.50
where

PWR = Power Generated in kw/h at terminals
STM = Process Steam from pass-out in t/hr
BLR LOAD = Steam Generated in the boiler in t/hr.

Operating Range:

PWR	4500 to 10000	kw/h
STM	0 to 100	t/hr
BLR LOAD	110	t/hr maximum.

Optimisation Methodology:

If P1 & S1 are power generated & pass out steam from turbine 1 ,P2 & S2 are power generated and pass out steam from turbine 2 respectively and load1 & load2 are the steam load in each boiler in t/hr ,utility optimisation could be carried out by either **LP or NLP** models as given below.

From CHP model

load 1 = 0.02737 * P1 + 1.85148 * S1 - 185.59731
load 2 = 0.02737 * P2 + 1.85148 * S2 - 185.59731
fuel 1 = fn (load 1)
fuel 2 = fn(load 2)

From Demand Model

Total Power Demand = P1+P2
Total Steam Demand = S1+S2

Objective Function:

minimise fuel 1+ fuel 2

subject to
P1+P2 > = PWR DEMAND
S1+S2 > = STM DEMAND
P1,P2,S1,S2 > = 0

While this could be solved by LP modelling technique such as Simplex , Evolutionary Operations Model could be deployed using the actual operating data P1 ,P2 ,S1, S2 ,load1, load2 ,fuel 1 & fuel 2. In this system, it is assumed one set of boiler and turbine are taken as stand-by equipments .This methodology could be applied to any set of boilers and turbines .

Monitoring Steam Consumption & Losses:

Utility cost is determined by Boiler Efficiency, Steam Consumption in the down stream units and major rotating equipments such as compressors, turbines , steam leaks from valves ,flanges ,vents etc .Using the actual operating data , it is possible to assess the performance of rotating equipments by modelling technique . A few models related to boiler and turbine are given in the next page .

a.Boiler Efficiency vs Load Factor

Polynomial Model

load factor	*X1*	*observed efficiency*	*simulated efficiency*
120	120.0000	90.2000	90.0209
110	110.0000	90.4000	91.0091
100	100.0000	91.2000	90.6126
90	90.0000	89.0000	88.9529
80	80.0000	86.0000	86.1516
70	70.0000	82.0000	82.3301
60	60.0000	78.0000	77.6100
50	50.0000	72.0000	72.1129

Model Error of Estimate : .3617834 %

This is based on Polynomial Model of the form

blr_eff% = A3*X1^3+B3*X1^2+C3*X1+D3

X1=load factor of operating boiler

A3 =-2.025601E-05: B3 =-2.391636E-04
C3 = .7603482 : D3 = 37.22542

b.Turbine Performance Model based on Operating Data (base case)

$$\text{Power} = 2.864448\text{E-}08 * (\text{flow})^{.64983}\ (\text{rpm})^{2.15599}\ (\text{press})^{.16322}$$

where

flow = steam flow in kg/hr
rpm = revolutions / minute
press = steam pressure in kg/cm2 g

c..Pressure Correlation Index for trouble shooting turbine problems: *(ref 30,29,14)*

More often turbines develop problems due to soluble and insoluble deposits.Soluble deposits are minerals of calcium ,Magnesium etc and are generally deposited in the high pressure and intermediate pressure range. Silica sediments deposit at the end of the intermediate pressure zone or low pressure zones of the section . Deposits reduce flow area and reduce power output. Certain operating parameters could be identified to develop *(ref 9,10,11)* these models and may be used to identify the problem area more easily.

A typical model is given below for monitoring this.

Parameters used in the model are steam inlet & outlet pressure in kg/cm2a , steam flow in kg/h ,and power output in kw or mw .

An index known as pressure correlation index is used from the above data which is given by

$$\textbf{pci} = [p1^2 - p2^2] / [S^2]$$

where P1,P2 are i/l ,o/l pressures at turbine , S steam input in kg/hr/kw and pci is pressure correlation index.An actual trouble shooting application based on the observed parameters is given below in fig 7.03.

Pressure Correlation Index Model

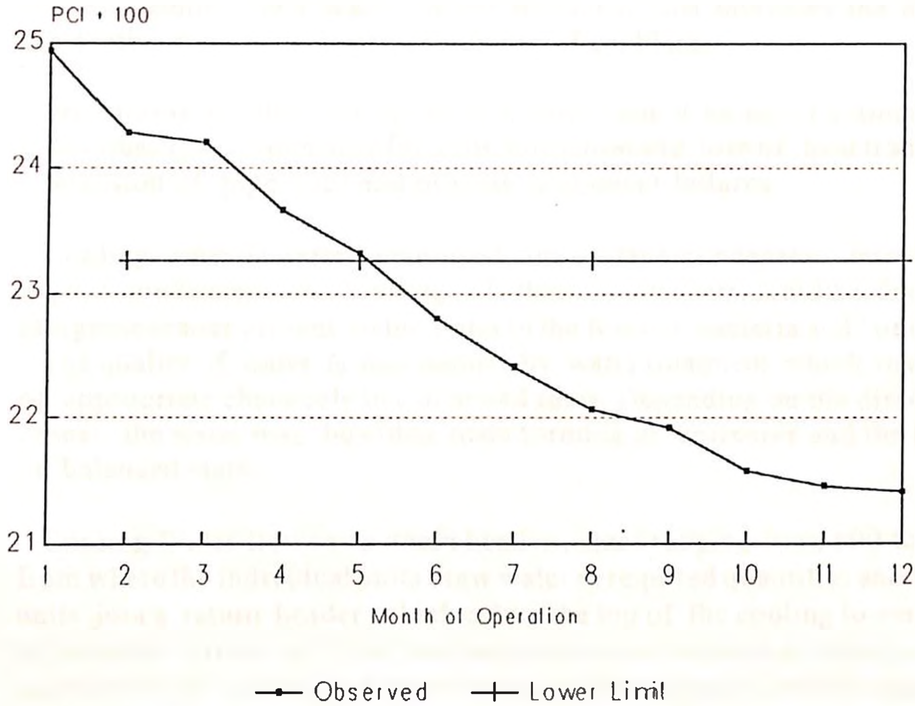
pci = a3*x1^3+b3*x1^2+c3*x1+d3

where pci = index

x1 = month of operation
a3 = 2.303709E-03: b3 = -2.888406E-02
c3 =-.3006952 : d3 = 25.19103
Model Error Range : 0.0819

It may be noted that after the fifth month of operation, the index has started coming down below the permissible limit and needs an investigation.

fig 7.03 Turbine Performance Monitoring Using Pressure Correlation Index



d.Model for Steam Leaks Estimation

Steam leaks play a major role in the utility cost as every kg of steam is a value added product which includes the cost of fuel , bfw and chemicals added besides labor cost and other fixed costs . Steam leaks could be quantified to some extent from the plume length of the leaky contour. The model that uses this parameter in steam leak estimation is given by

$$s = 2.5678 * \exp^{(1.845 * L)} \quad \textit{(ref 30)}$$

where s is steam leak in kg/hr and L is plume length in metres. This methodology could be adopted to estimate the total quantity of steam leaks in the entire industry area wise, equipment wise and category wise for taking corrective action to control the utility cost and taking maintenance actions at the right time..

Cooling Water System

Cooling water ,which forms one of the major utilities in the process and power industries is a very important utility from cooling and utility cost point of view. Water is also used for drinking , generation of steam by treating the fresh water to Boiler Feed Water. Water treatment cost increases the utility cost and ineffective treatments lead to a number of problems .

Monitoring of the cooling water quality cannot be under estimated as cooling water quality is responsible for scale formation and loss of heat transfer efficiency , corrosion of pipe lines and process equipment failures.

Cooling water is extensively used in surface condensers, inter-stage coolers, vapour condensers etc. Fouling of these condensers could be due to organic or inorganic matter present in the water in the form of bacteria and / or dissolved salts . The quality of water is maintained by water treatment which involves addition of appropriate chemicals in calculated rates. Depending on the dissolved salts and gases , the water may be either scale forming or corrosive and the water must be in balanced state.

Cooling Water flows in a main header , sizes ranging from 600 to 1000 cms dia from where the individual units draw water in required quantities and the outlet from units join a return header which enters the top of the cooling tower and is cooled by counter current air flow *.The entire flow circuit is prone to fouling or corrosion and depending on the location,* and the process problem depends on the magnitude of the fouling / corrosion of the section.

Water Management:

The objective of water management is to

* minimise water consumption
* reduce water wastage
* eliminate scale formation and corrosion
* minimise water treatment and utility cost
* identify system condition and approriate tretment programmes.

All these activities have cost implications and hence monitoring the actual performance of the complicated system warrants using computer-based models.

a.Specific Consumption Model:

Specific Consumption of cooling water controls the operating cost by reducing electric power in cooling water pumps, fin-fan load , cooling water treatment cost and blow down rates. This cost may be dominant in water-scarce areas. A typical specific consumption model for a cryogenic section of the plant is given . Such models could be developed for all the process units and compared with actual consumption *for remedial action.*

$$cw = a * cu^3 + b*cu^2+c*cu+d$$

where

cw is specific consumption of water in m3/t feed

cu is capacity utilisation or load factor of the unit in %

a,b,c&d are constants equal to

2.371822*10^-6,-5.630864*10^-4,4.260005*10^-2 &
-0.8228692 respectively.

b.Trouble shooting :

Computer-based models may be used for trouble shooting cooling water problems associated with corrosion and scaling. Conventional techniques of monitoring Scaling / corrosion tendency include

*pressure drop measurements
*corrosion coupons
*iron count monitoring etc.

When corrosion rates are observed high, the water quality may be observed to be in the corrosive range and vice versa.Hence for effective corrosion/scale control, the water quality is monitored by associated parameters like tds,Calcium Hardness, P alkalinity, M alkalinity, water pH, temperature etc.

A simple multi -variable model that could be used for identifying corrosivity or scale forming tendency is given by *(Ref 62)*

$$LI = a+(-0.01844* t+2.5058) +(1.006578 \log ch - 0.4081191) + (1.006578 \log M - 0.0081191)$$

where

LI = Langlier Index
t = cooling water temperature in oC
ch = calcium hardness of water in ppm
M=methyl orange alkalinity in ppm
a = constant = 0.1 for tds < 300 & 0.2 for tds > 300

Using the above model, LI has been arrived at and the value of LI is used to estimate corrosion or scale forming tendency by a polynomial model as shown below.

corrosion
mpy = - 0.1504*(LI) - 0.5160* (LI) -0.9674*LI + 2.9849

Standard Error of the model : 0.5270

If LI is negative, the system has scale forming tendency & if LI is positive, corrosion is dominant as given below. Situation 1 & 2 indicate scale formation while situation 4 shows extreme corrosion rate follwed by 3 & 5.

Lang index	*Z1*	*Simulated corrosion*
2.0	2.0000	-2.2172
2.5	2.5000	-5.0088
-2.9	-2.9000	5.1189
-5.0	-5.0000	13.7219
0.0	0.0000	2.9849

This is applicable only for inorganic fouling and corrosion. If the observed conditions are not following the model, this could be due to bio-fouling and / or boilogical corrosion due to iron reducing / sulphate reducing bacteria . Even this situation could be estimated by using the cooling water related parameters like bod , loss on ignition , chlorine demand etc .

c.Monitoring Pressure and Temperature Data :

Proper logging of temperature and pressure data of cooling water sections especially across coolers and condensers offers tremendous advantage in monitoring the fouling and or corrosive situations. Inorganic fouling is basically a function of time and the fouling rate is often reflected in the outlet temperature of the hot stream.

It is possible to generate performance models for the condensers which could be used for *predicting the time at which the fouling will reach the maximum* . For arriving at this decision , certain base case conditions will have to be used in the model as given below .

A typical fouling model is of the form *(ref 63)*

$$R=Ro^* [1 - e^{-A^*t}]$$

where R = is the fouling resistance at any time
t = in hours from base time
Ro = fouling resistance at base conditions
and A the constant for the system.

From the operating data , a model could be developed for knowing the fouled state of the system and this info could be used for tube cleaning or replacement decisions. This is also used for optimum cleaning time for the condensers / coolers. A typical model is given below to explain it's application.

Data:

R1,T1 .00010,20
R2,T2 .00015,100

Model:

$$R = 6.755932E\text{-}04 * [1 - e^{-8.009498E\text{-}03 * T}]$$

Prediction:

hrs	*resistance*	*h.t.coefft*
150	4.723981E-04	2116.859
200	5.394521E-04	1853.733
300	6.144791E-04	1627.395
400	6.481589E-04	1542.832
700	6.731115E-04	1485.638

The above model could be used for developing an optimum cleaning time model at which the total cost will be minimum.

Conclusion:

Utilities Management include compressed air , refrigeration , fuel etc . The same modelling methodology could be used effectively for developing performance models for the total system as explained above. The basic advantages of using the model is that it simplifies a complex problem into quantifyable data for interpretation. Hence action could be taken in the right direction after checking the validity of the models so developed even by an inexperienced operations engineer .

Since these models are based on actual operating data and are developed by experienced technical personnel , these models may also be used for training and design purposes and also for product development . However variables used in these EORT / Statistical Models must be chosen with great care to avoid duplication or strongly related variables.

When once developed and implemented, this could save considerable time and money and other valuable resources and improve the productivity of the overall system due to better operation, long run lengths, minimum failures, planned maintenance, minimum operating cost etc.

Process Decisions Application

Process Engineering section is the real brain behind the productivity of the enterprise. Many decisions are linked to process decisions. EORT models are successfully used to take corporate decisions , monitoring process performance such as the energy consumption pattern of the individual unit ,trouble shooting process operation such as liquid - liquid extraction etc. The principle of EORT modelling was covered in chapter 5 with a number of examples.

Effective & result oriented operation of the Industry is governed by the quality of process decisions from process and production planning to trouble shooting plant problems.In a complex industry like petroleum refining, these decisions are dynamic and change from time to time. No decision is consistent at any point of time because of the diversity in feed stocks processed, process mix,capacity availablity, plant break downs, equipment failures, process problems, catalyst activity ,imposed quality constraints, environmental regulations etc.Overcoming these problems involve thorough process analysis which refers to the application of Scientific Methods to the recognition and definition of the problems and development of procedures for their solution.

This means

i. Mathematical Specification of the problem for the given physical situation.

ii. Detailed analysis to obtain mathematical models

iii. Synthesis and presentation of results to ensure full comprehension.

This activity is cost intensive and is to be tackled within a stipulated time-frame.

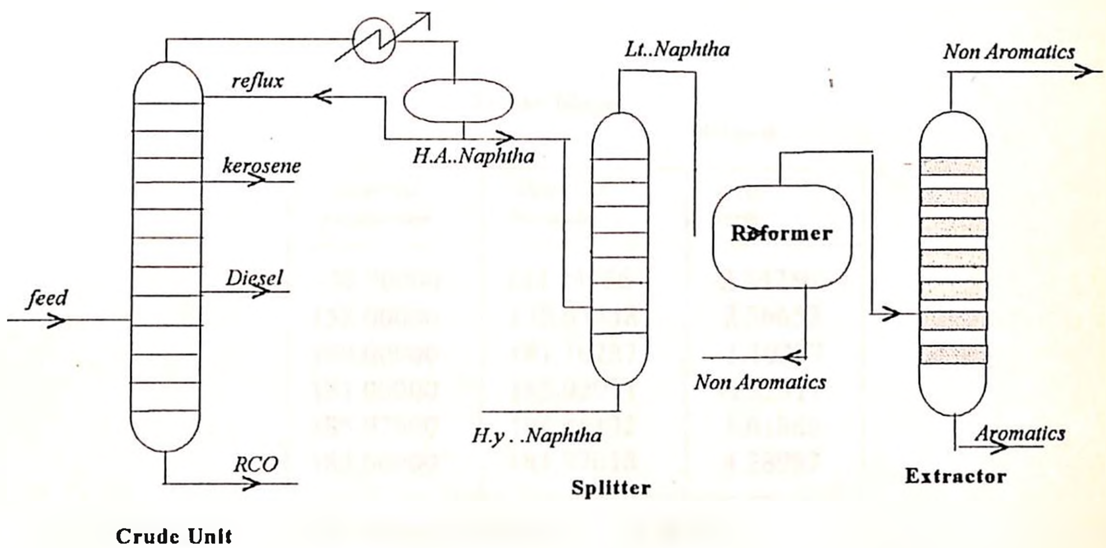
Under these conditions, Computer Aided Decision Support System (**CADSS** in short) may be of immense help for taking the right decision at the right time. Most of the applications are based either on process simulation or performance modelling or a combination of the two.

This chapter covers some specific applications related to corporate planning which develops long range corporate strategies to maximise profits to the enterprise. A few process applications are also covered in this chapter. These are all live examples with real life data pertaining to a refining industry.

Case Study:

A refinery processes 4 types of crudes A ,B,C & D. Each crude contains a certain % of light aromatics which are reformed and extracted in the petro chemical unit. Precursor availability in the feed stream determines aromatics production which is a function of capacity utilisation, feed mix and stream days. A block flow diagram of the process is is shown in fig 8.01..

Fig 8.01. Typical flow diagram of an Aromatics Recovery Unit



This model is used to determine the impact of all the above parameters to determine the production quantity of aromatics so as to maximise the profits to the industry.

No of data sets used in the model : 6
Independant variables used in the model : 3

Variables used in the linear model are:

variable 1 is feed
variable 2 is mix
variable 3 is stream days
variable 4 is aromatics

Observed Data

feed '000 t	*mix % A*	*stream days*	*aromatics '000 t*
4761.00	62.00	337.69	138.00
4616.00	69.80	329.20	152.00
5006.00	73.30	355.10	180.00
4843.00	74.00	333.40	181.00
5122.24	70.90	360.80	185.97
4861.49	71.03	333.19	185.66

Linear Model

'000 tons

observed production	*calculated by model*	*error term*
138.00000	140.24286	-2.24286
152.00000	149.63348	2.36652
180.00000	181.10287	-1.10287
181.00000	185.92911	-4.92911
185.97000	184.35132	1.61868
185.66000	181.37018	4.28983

S.E. of the estimate = 3.38130

Non Linear Model

138.00	139.74846	-1.74846
152.00	149.40695	2.59304
180.00	181.07817	-1.07816
181.00	186.67909	-5.67914
185.97	184.11577	1.85425
185.66	181.57655	4.08344

S.E. of the estimate = 3.55834

Sensitivity Analysis:

The planner estimates that in future years to come, the % of feed stock A available will be limited to a maximum of 50% only. *What will be the scenario under these conditions ?* **Table 8.01** *answers these questions.*

feed	mix%	stream days	estimated by linear	non linear
5000	50.00	345	134.6500	127.6937
5000	45.00	350	116.5181	110.0792
5000	55.00	350	141.1481	136.7593
5000	50.00	360	117.1994	115.3106
5200	45.00	340	155.3212	137.8033
5100	40.00	340	129.4216	112.3521
5000	45.00	355	110.7013	106.3996

This could be used to identify the impact of feed mix & on stream factor on the production of speciality product which is crucial for the profitability of the refinery. This may be used for monitoring process performance also as given below.

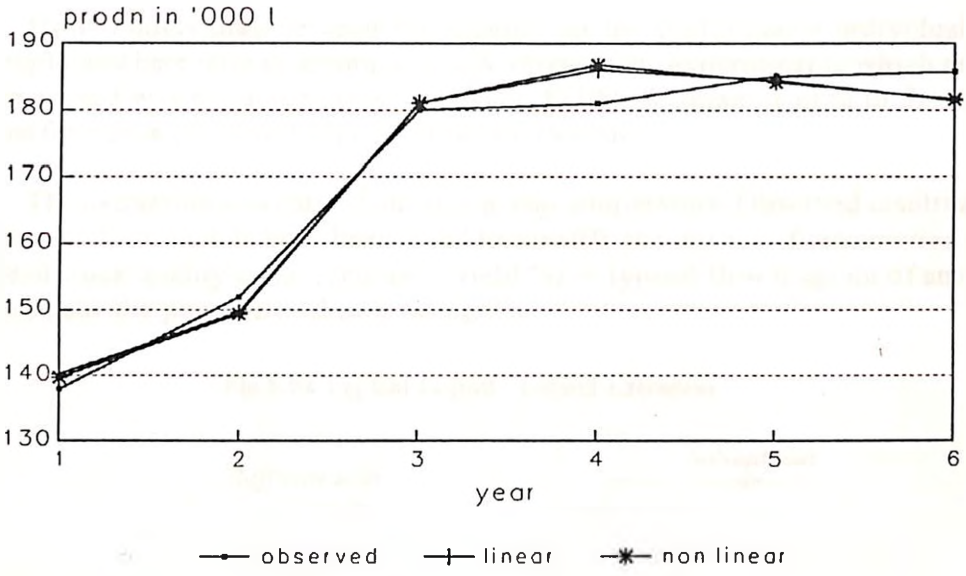
The predictive power may be improved upon further by considering other relevant factors such as no of power outages ,break-downs, shut down days etc which affect the production process directly.

Table 8.01. PERFORMANCE EVALUATION

feed	mix%	stream days	estimated by model avg	observed
5000	50.00	345	131.1718	119.0000
5000	45.00	350	113.2986	95.7000
5000	55.00	350	138.9537	114.7800
5000	50.00	360	116.2550	92.4500
5200	45.00	340	146.5622	102.0000
5100	40.00	340	120.8868	91.0000
5000	45.00	355	108.5504	87.5900

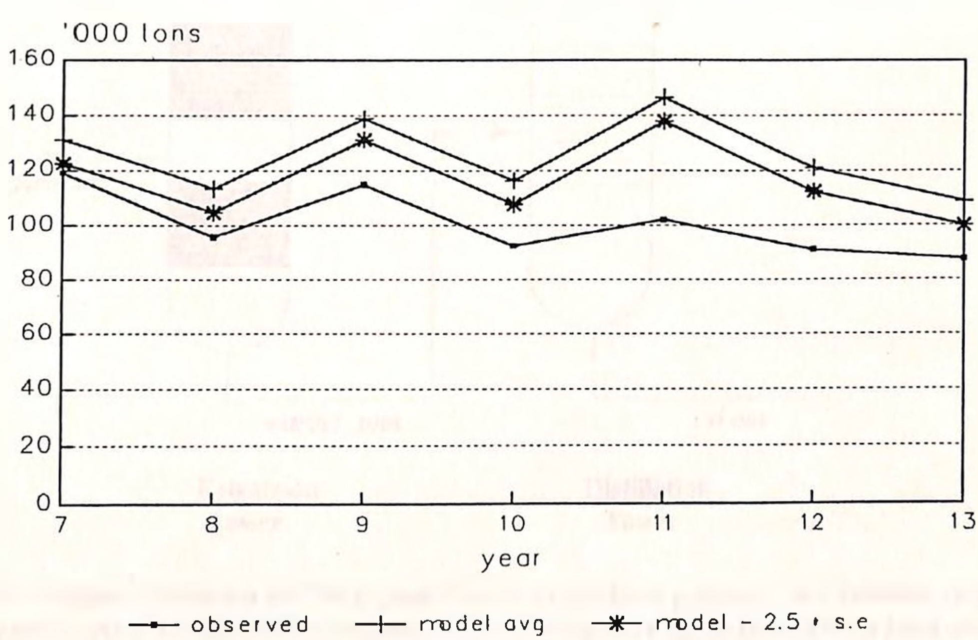
Fig 8.02 & 8.03 explains the details of plant performance for the observed set of data. Considering the standard error of estimates, it may be noted that actual performance of the *plant shows signs of deterioration.* The resons could be power failures, performance of extractor, product quality, feed quality, solvent deterioration etc. It is possible to include these variables also in the model to pinpoint the impact quantitatively for trouble shooting process problems and corrective action

Fig 8.02. Plant Performance Model
(variables t'put,feed mix,streamdays)



s.e 3.38,3.55

Fig 8.03 Simulation for new conditions



(note plant performance deterioration)

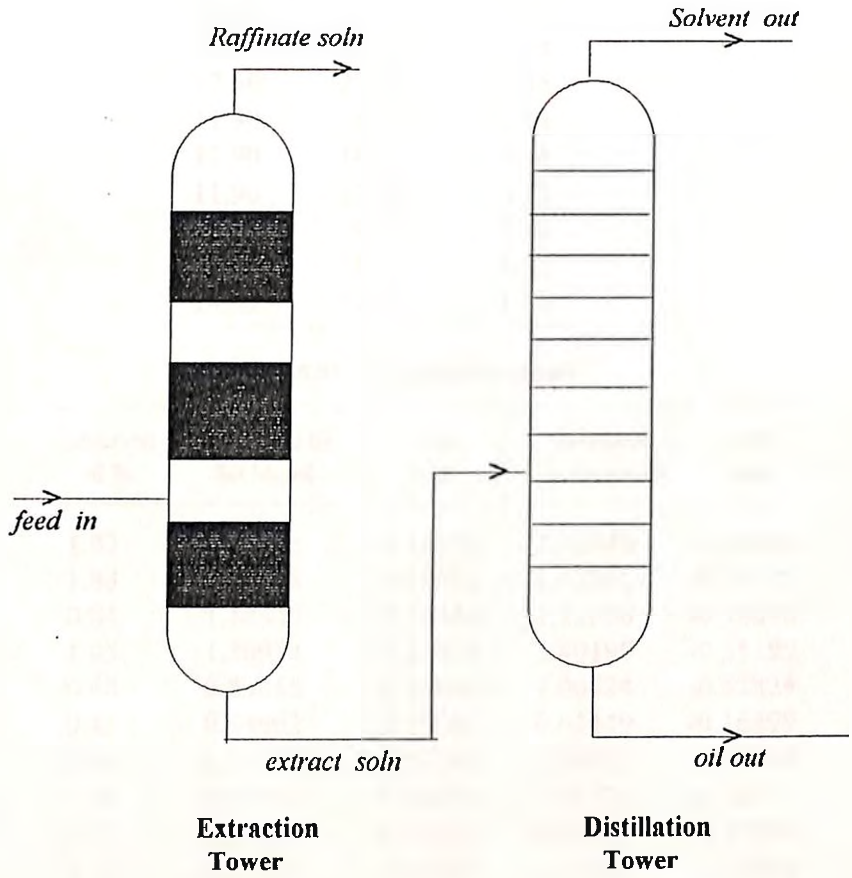
II . Liquid - Liquid Extraction Performance Model

Case Study :

How models may be used for monitoring the performance individual unit is explained here with an example which refers to an experiment in which oil present in a feed was extracted using a solvent. EORT program is used to determine the performance of liquid-liquid extraction system .

The extraction was carried out at constant temperature. Observed results are given below. Two models have been used to identify the impact of *solvent / feed ratio* and feed stock quality on oil recovery (yield %). A typical flow diagram of an extractor used for the purpose is shown in fig 8.04 .

Fig 8.04 Typical Liquid - Liquid Extractor



In normal operation of the liquid-liquid extraction process, the solvent required for extracting the oil content in feed stock is proportional to the oil% in feed and also the flow rate of feed for a constant extraction temperature. For easier understanding, this is taken as *solvent / feed ratio*. Feed and solvent rate determine contact time for a given size of extractor.EORT models may be used to determine extraction efficiency for a given feed , solvent/feed ratio and temperature.

1.No of data sets used in the model : 12
2.Independant variables used in the model : 2
3.Variables used in the Scientific model are ......

variable 1 is % oil in feed
variable 2 is vol of solvent cc/gm
variable 3 is % residual oil

Input Data

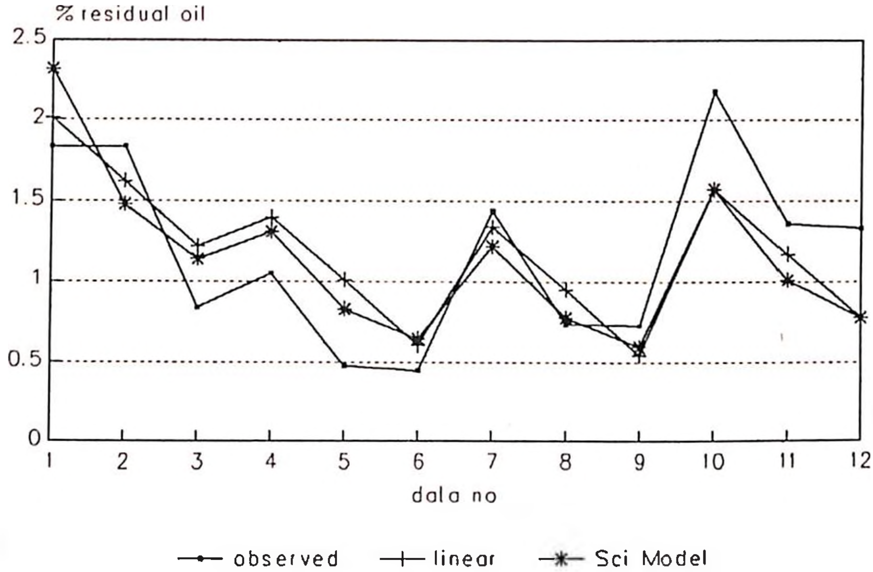
% oil in feed	solvent in cc/gm	% residual oil
19.69	9.30	1.83
19.69	18.60	1.83
19.69	27.90	0.84
12.60	9.30	1.05
12.60	18.60	0.48
12.60	27.90	0.45
11.90	9.30	1.44
11.90	18.60	0.74
11.90	27.90	0.73
14.55	9.30	2.18
14.55	18.60	1.36
14.55	27.90	1.33

Table 8.02 **Program output**

observed oil %	simulated by Sci.Model	error term	simulated by lin model	error term
1.83	2.31755	-0.48755	2.01440	-0.18440
1.83	1.48408	0.34592	1.62065	0.20935
0.84	1.14347	-0.30340	1.22690	-0.38690
1.05	1.30934	-0.25934	1.40199	-0.35199
0.48	0.83845	-0.35845	1.00824	-0.52824
0.45	0.64602	-0.19602	0.61449	-0.16499
1.44	1.21703	0.22297	1.34152	0.09848
0.74	0.77934	-0.03934	0.94777	-0.20777
0.73	0.60048	0.12952	0.55402	0.17598
2.18	1.57392	0.60608	1.57042	0.60958
1.36	1.00788	0.35212	1.17667	0.18333
1.33	0.77657	0.55343	0.78292	0.54708

Standard Error
of the estimate = 0.37529 0.36255

Fig 8.05. EORT Models for Solvent Extraction Process



While the program output shown in previous page gives an estimate of oil % or extraction efficiency for various conditions, **fig 8.05** explains the behaviour of extraction process under constant temperature . The accuracy may be improved upon by adding temperature as one of the variables in the model. These models are amenable to 'what-if' analysis and hence forms a decision basis for process monitoring and / or retrofit or revamp decisions.

III. Plant Performance Models for Utilities , Energy and Losses.

case study:

EORT models may be used to determine the plant performance in terms of fuel, steam , power , total energy , solvent consumption and also process loss during operation. Since capacity utilisation plays a major role in the consumption of resources , these models may be used to identify the % capacity utilisation at which the profits could be maximum. Program outputs are given in **tables 8.03 through 8.07 and fig 8.06 through 8.13.**

Many foreign companies like BP , Caltex , Exxon, Chevron etc use this approach to determine the overall plant performance of process units. This program is capable of giving the limits of capacity utilisation at which the energy consumption / losses could be minimum. Using the coefficients of each model and the cost of each resource, it is possible to build an overall cost / profitability model from the data . Continuous process monitoring using these models help in identification of process deterioration for remedial action.

PROCESS UTILITY CONSUMPTION MODELS

a. file name : c:\techplan\enrgy.out
base value for X variable : 0

Table 8.03 Fuel Consumption Models

T'put	*fuel actual*	*linear*	*model values* *exponen -tial*	*non linear*	*polynom -ial*
1000	20.0000	18.9873	19.0889	19.7920	20.1536
960	18.2400	18.1937	18.1132	18.2271	17.9636
870	14.7900	16.4081	16.0962	15.3275	14.9482
675	12.7500	12.5393	12.4635	11.9977	12.6881
598	11.3600	11.0117	11.2661	11.7956	11.3866
S.E		0.8731	0.7271	0.4665	0.1610

Model Output for New Data

t'put	*linear*	*exponen tial*	*non linear*	*poly-nomial*
620	11.4481	11.5960	11.7891	11.8626
900	17.0033	16.7423	16.1984	15.7071
985	18.6897	18.7170	19.1852	19.2596
1050	19.9792	20.3828	21.9873	23.8425

Table 8.04 . Power Consumption Model

t'put	*actual MW*	*Model Estimates* *linear*	*exponentl*	*non lin*	*polynomial*
1000	150.0000	151.0023	152.5789	150.2065	151.4129
960	147.0000	145.3429	145.5498	145.3099	144.4308
870	130.9000	132.6093	130.8958	133.6778	132.4125
675	108.5000	105.0199	104.0094	105.5554	107.8584
598	91.7000	94.1256	94.9825	93.3505	91.9860
S.E	:	2.2211	2.8176	2.0981	1.5085

Model Output for New Data

t'put '000t	Estimated Power Consumption by model linear	exponentl	non lin	polynomial
620	97.2383	97.4785	96.9012	97.1466
900	136.8539	135.6087	137.6497	136.0106
985	148.8800	149.9040	148.3900	148.6380
1050	158.0765	161.8444	156.0909	162.2799

Table 8.05 Steam Consumption Model

t'put '000 t	steam '000 t	estimated steam by model linear	exponentl	non lin	polynomial
1000	250.0000	246.8428	247.5132	255.6826	256.1703
960	249.6000	238.3115	237.4873	238.6785	238.3231
870	200.0000	219.1161	216.3889	207.2471	206.7355
675	175.5000	177.5262	176.8844	171.5773	172.5084
598	167.8000	161.1035	163.3505	169.7145	169.1628
S.E	:	10.5050	9.4150	6.6805	6.6546

Model Output for new data

t'put '000 t	Simulated Steam Consumption Linear	exponentl	nonlinear	polynomial
620	165.7957	167.1080	169.5406	169.6398
900	225.5146	223.2047	216.6738	216.0111
985	243.6435	243.7048	249.0872	249.1875
1050	257.5069	260.6429	279.5637	282.0661

Table 8.06 Models for Process Loss Estimation.

t'put '000 t	obs loss '000 t	Process Loss simulated by model Linear	Exponentl	Non-Lin	Polynomial
1000	7.2000	6.5241	6.4930	6.9292	7.1105
960	6.0900	6.3720	6.3311	6.3888	6.2567
870	5.4000	6.0298	5.9814	5.4859	5.2957
598	5.2100	4.9957	5.0376	5.3903	5.1853
675	5.3100	5.2884	5.2885	5.0158	5.3619
S.E	:	0.4426	0.4304	0.2404	0.1000

Output for New Data.

t'put '000	*simulated loss by model* Linear	Exponentl	Non Linear	Polynomial
620	5.0793	5.1080	5.2510	5.2878
900	6.1439	6.0957	5.7387	5.4924
985	6.4670	6.4318	6.7165	6.7538
1050	6.7142	6.7012	7.7250	8.6552

Table 8.07. Solvent Consumption Models

t'put '000 t	*Solvent '000 t*	*Simulated Consumption by models* Linear	Exponentl	Nonlinear	Polynoml
1000	5.0000	4.5849	4.5827	4.9408	4.9645
960	4.3200	4.3876	4.3444	4.4023	4.3850
870	3.4800	3.9437	3.8524	3.4658	3.4408
675	2.7700	2.9819	2.9691	2.7423	2.7878
598	2.9300	2.6021	2.6790	2.9488	2.9218
S.E	:	0.3299	0.2884	0.0482	0.0385

Output For New Data.

t'put '000	*Simulated Solvent Consumption by models* Linear	Exponentl	Nonlinear	Polynoml
620	2.7106	2.7589	2.8614	2.8662
900	4.0916	4.0098	3.7357	3.7034
985	4.5109	4.4919	4.7300	4.7349
1050	4.8315	4.8992	5.7195	5.8416

Note: In actual operation, process loss,steam ,power,fuel consumption etc are governed by the capacity utilisation of the individual plants and are dynamic. Under these conditions, mathematical models offer a *very good decision support to monitor the performance individually or in totality as given above .*

Fig 8.06 Fuel Consumption Model
(For an aromatics unit)

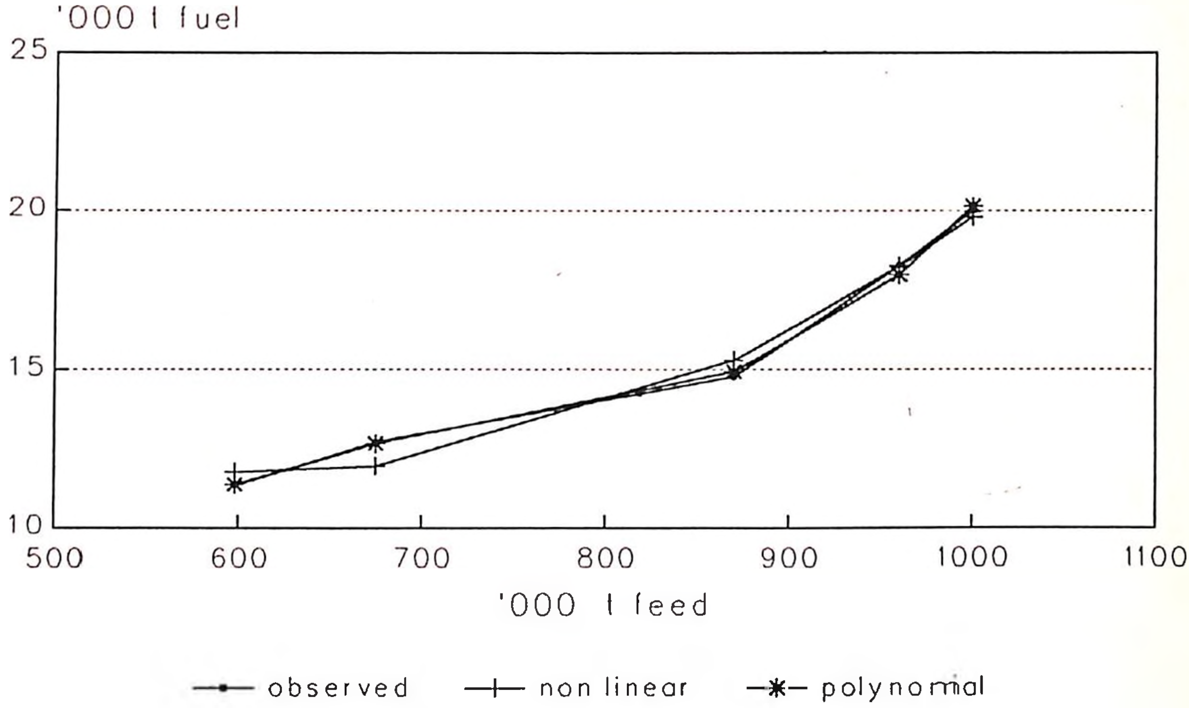
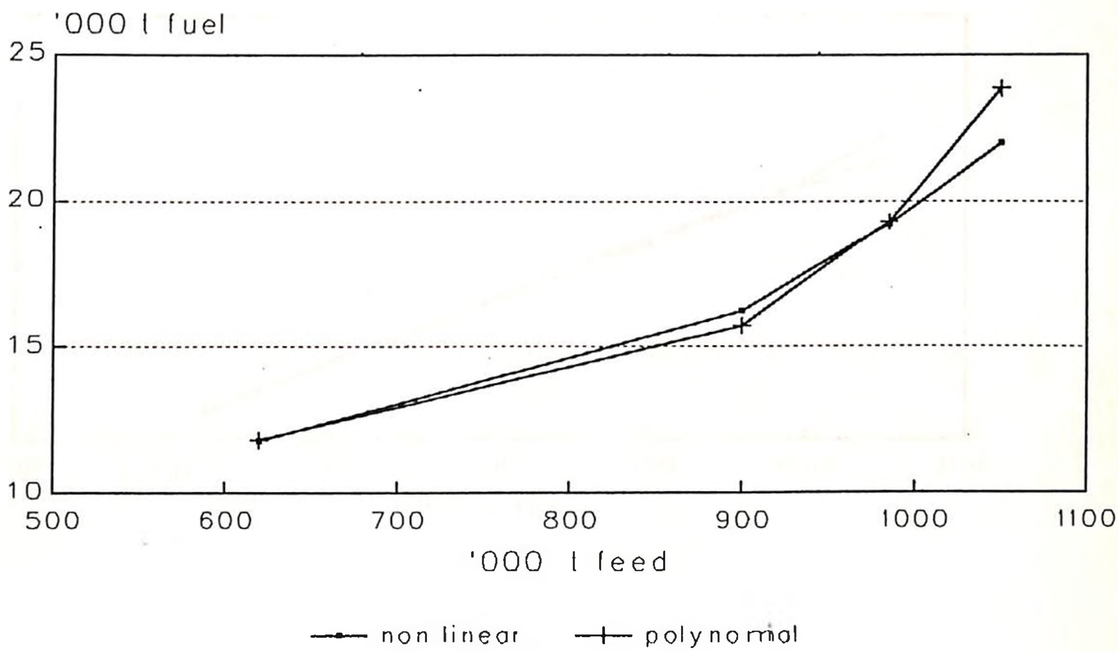


Fig 8.07: Simulated Fuel Consumption
(by flexi targetting)



for new t'puts

Fig 8.08. Power Consumption Model
(For an aromatics unit)

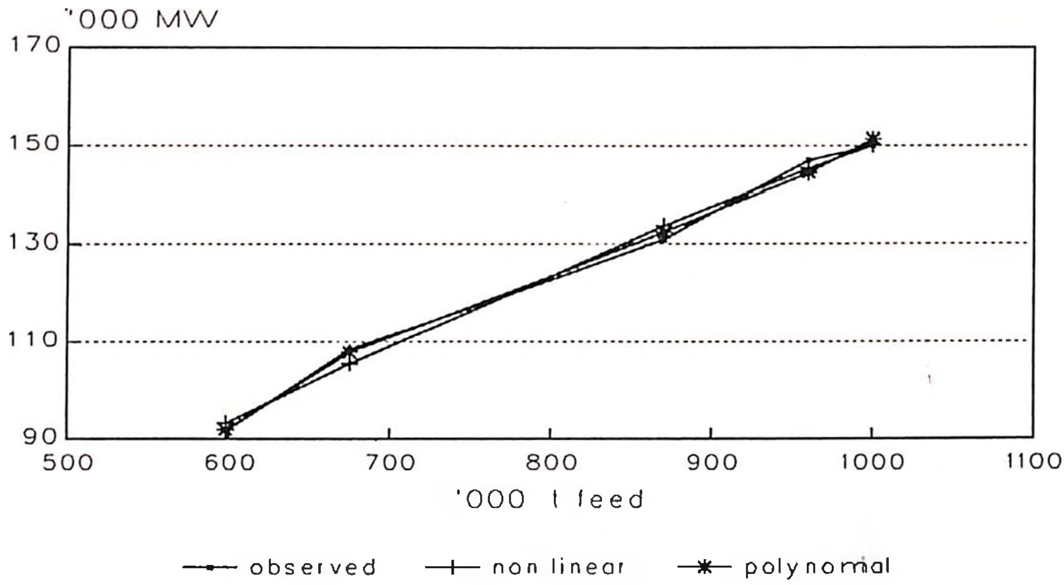


Fig 8.09. Simulated Power Consumption
(For new conditions)

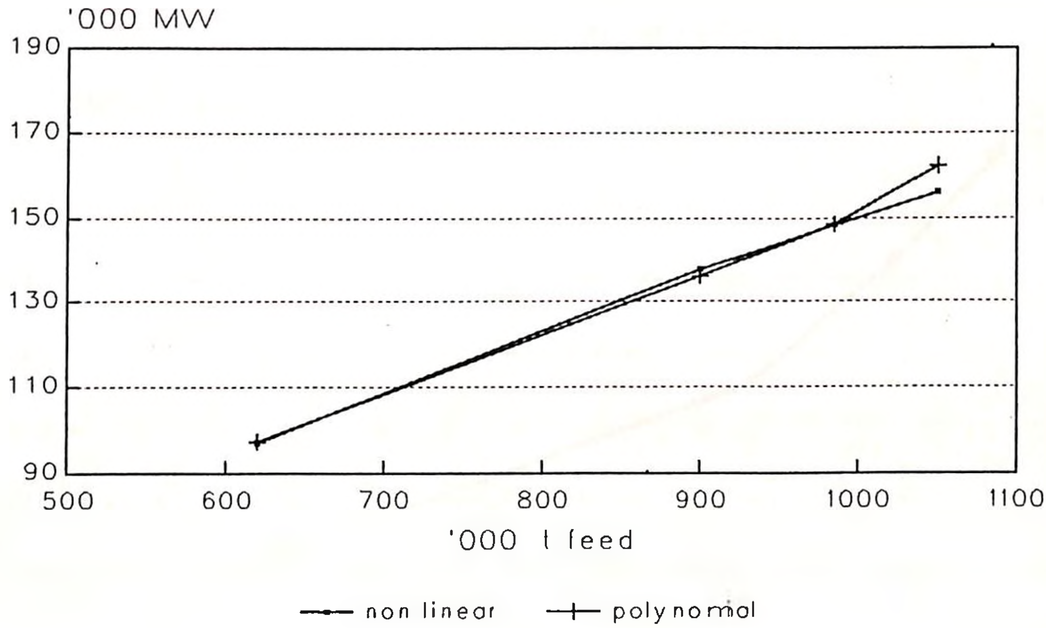
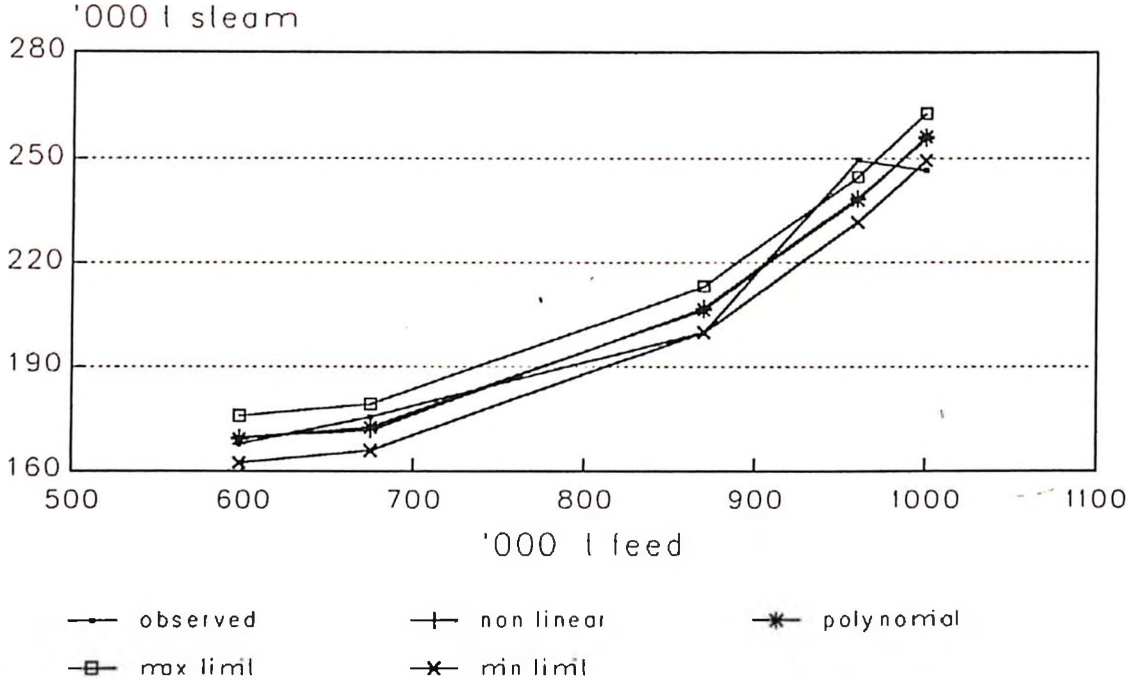


Fig 8.10 Steam Consumption Model
(For an aromatics unit)



S.E 6.68, 6.65

Fig 8.11. Simulated Steam Consumption
(For new conditions)

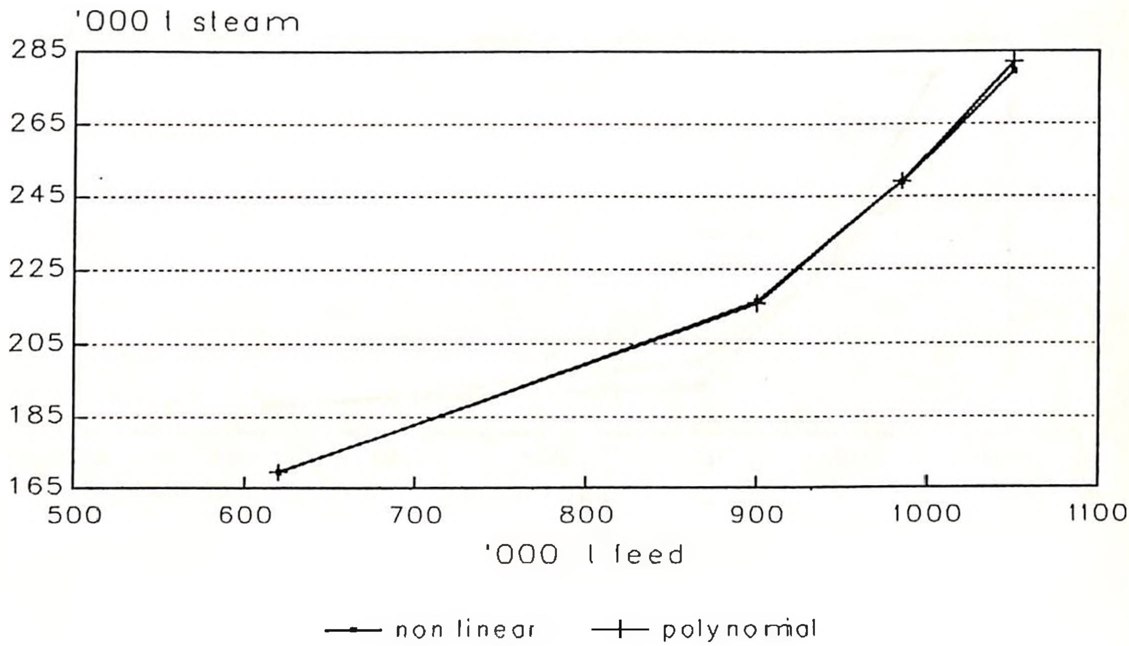
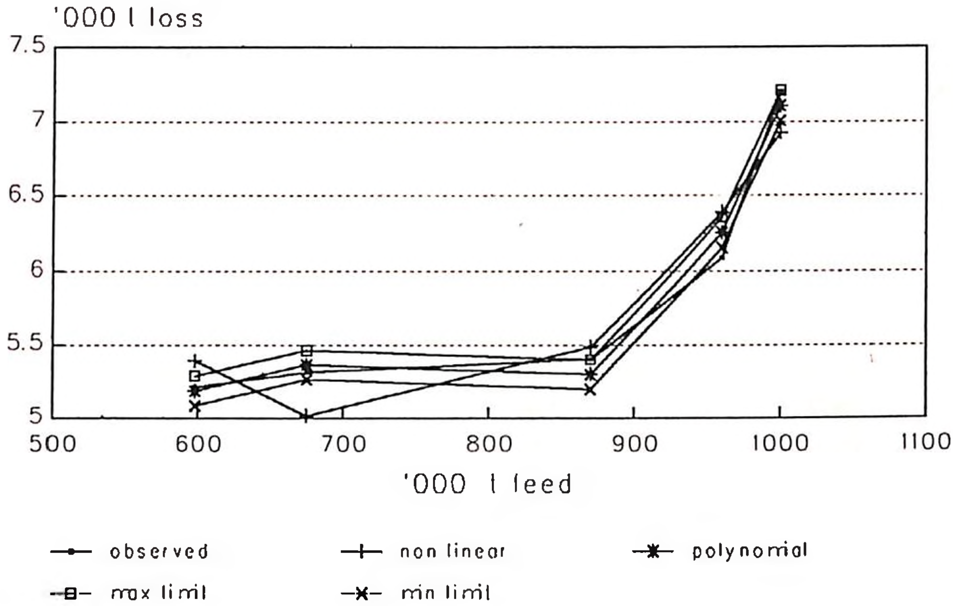
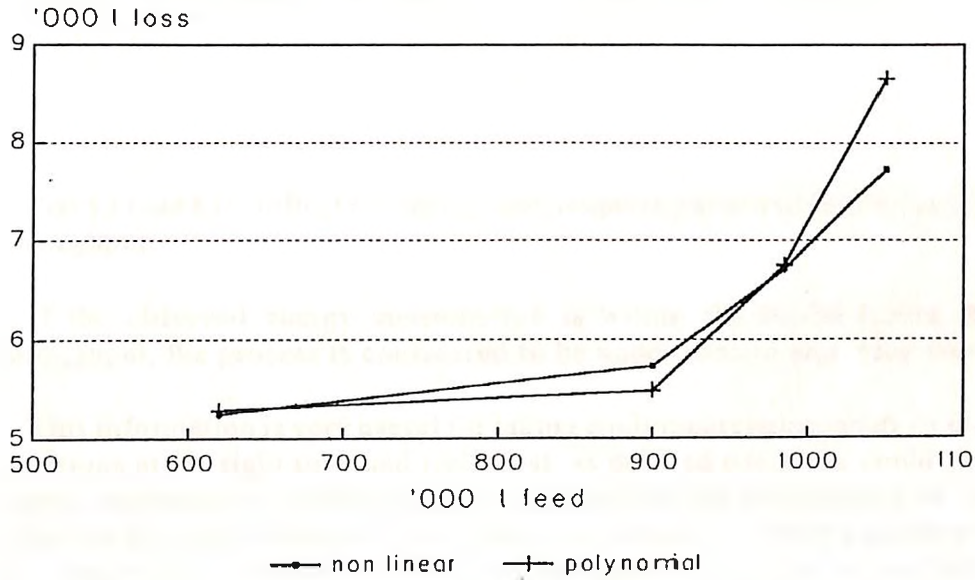


Fig 8.12. Model for Process Loss
(For an aromatics unit)



S.E 0.2404,0.1000

Fig 8.13. Simulated Process Loss
(For new conditions)



IV. TOTAL ENERGY CONSUMPTION MODEL FOR AN AROMATICS UNIT

This program gives the total energy consumption model for an Aromatics unit which consumes energy in the form of fuel, steam and electricity. The consumption may be monitored by a standard fuel equivalent *SRFT* (*standard refinery fuel in tons)* having a calorific value of *10000 kcal / kgm of fuel. The output is given in* **table 8.08.**

Table 8.08 . Total Energy Consumption Models

t'put '000 T	actual '0 SRFT	Simulated Energy Consumption Lin	Expon	Non lin	Polynomial
1064	9946.00	10054.28	9964.99	10676.52	10083.37
1359	10060.00	11225.75	11231.97	10985.93	11237.20
1386	11531.00	11332.97	11355.69	10911.95	10578.61
1165	11971.00	10455.36	10381.81	11013.00	11597.69
775	8467.00	8906.63	8862.47	8387.58	8478.15
S.E	:	883.22	904.05	734.61	700.17

Simulated for New Conditions

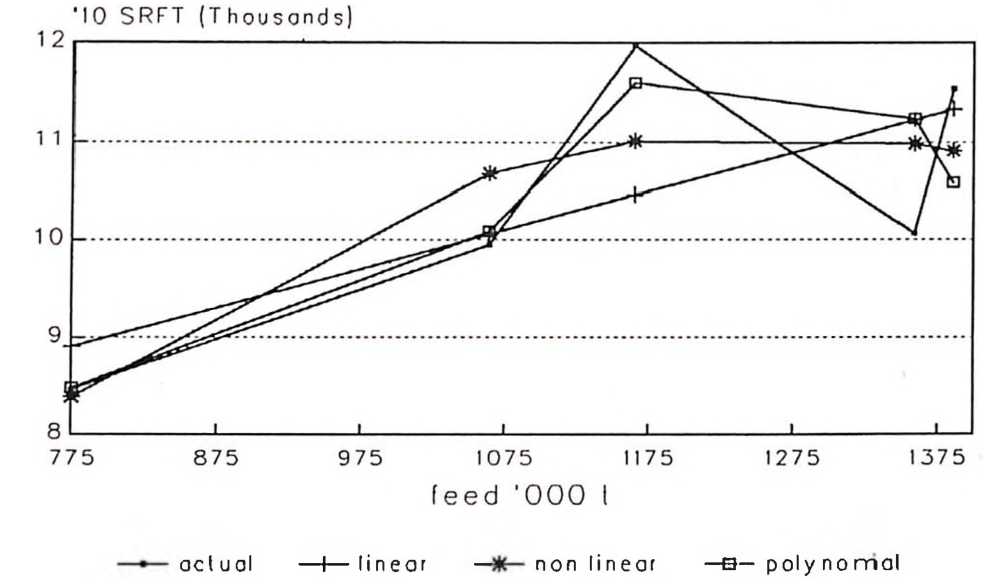
t'put '000 T	Simulated Energy Consumption by models Linear	Exponentl	Nonlinear	Polynomial
850	9204.4658	9136.2959	9170.4463	7802.2437
1050	9998.6846	9908.5527	10610.9414	9850.7783
1250	10792.9033	10746.0859	11110.1514	12208.9746

Figs 8.14 and 8.15 reflect the energy consumption pattern of the aromatics unit w.r.t throughput.

If the observed energy consumption is within the model limits for a given throughput, the process is considered to be under control and vice versa.

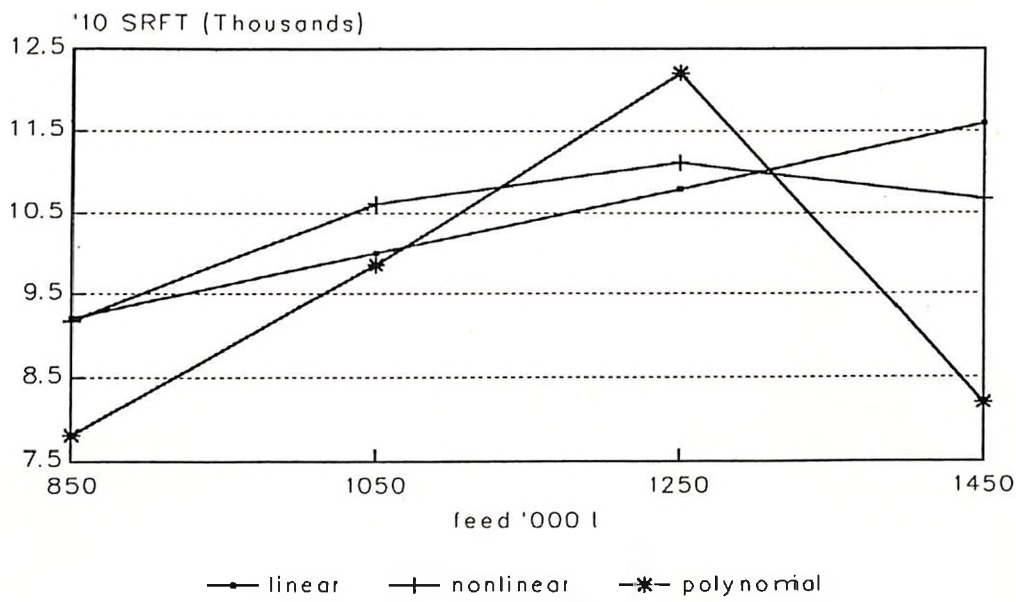
This information is very useful for taking equipment replacement or maintenance decisions at the right time and right cost as delayed decisions could increase the energy consumption drastically and even off-set the profitability of the process when the process operates under competitive situations. Quite a number of refineries had been shut down in US and other parts of Europe on account of poor profitabilty one of the reasons being high energy consumption, besides others *(ref 8,59)*

Fig 8.14. Model for Energy Consumption
(aromatics complex)



S.E 734.61,700.17

Fig 8.15. Simulated Energy Consumptio
(for new conditions)



Conclusions:

Above outputs cover only limited applications. It is possible to determine quantitatively the effect of varying process parameters , feed quality, catalyst composition etc on the objectives sought by the user. This technique is found to be an excellent tool for R&D activities and operational analysis. While the input data for these models are actual observed data , simulated outputs from process modelling software like *Chemshare,Hysim, SimSci* etc may also be used to determine the relationship between variables and compared with actuals for determining the process performance / efficiency .

Energy Management Applications

Energy consumption in many process industries constitute about 70 to 80 % of the total operating cost and hence needs constant monitoring. This is achieved by a computer-aided energy management system. Since process industries are often very large and complex and the number of sub-systems / units and equipment to be monitored are very large, the manager has to understand

* which is the critical unit that has to be monitored ?
* which are the equipments to be monitored more often ?
* what are the reasons for high energy consumption ?
* how to bring down the energy cost and so on.

To select a couple of equipment from among thousands, *an A,B,C analysis is often carried out applying Parato's theory*. From the design energy consumption rates of each equipment, about 10 to 15 % of the lot which consume nearly 75 % of total energy inputs are identified. When once these are identified, energy performance of each critical equipment may be monitored by all concerned. Class B equipments are accorded next priority and class C equipments are seldom monitored. This approach saves considerable time and other valuable resources and is more productive than conventional methods .

A decision flow diagram of this approach is given in **fig 9.01** . While in the earlier chapters models were developed based on statistical or mathematical techniques, energy management programs given here are invariably based on material and energy balance.

Case study: This covers energy management programs related to ABC Petroleum Corporation and is used for

* A,B,C analysis of energy consuming centres	- for control decision..
* Heat loss from heaters / boilers / hot surfaces	- for corrective action.
* Fuel Analysis and excess air for heaters / boilers	- for operational control.
* Heat loss analysis from heat transfer equipments	- for corrective action.
* Boiler / Heater efficiency	- for operational control
* Boiler / Heater efficiency from field data	- ,,
* Energy Consumption - classification	- planning & process development
* Scaling in Heat exchangers / coolers / condensers-	,,
* Heat Transfer equipment performance models	- for equipment maintenance or
* Boiler efficiency model	- replacement decisions.
* Turbo compressor models	- ,,
* Back pressure turbine evaluation etc	- ,,

Case Study:

ABC Petroleum Corporation comprises of Crude Distillation Unit, Vacuum Unit,Visbreaker, Fluid Catalytic Cracker, Naphtha / Kero / Diesel Hydro Desulfurisation units , Catalytic Reforming Unit , Aromatics Recovery Unit, Bitumen Unit, Delayed Coker Unit and Six Utility boilers . The company wants to launch an Energy Management Programme to identify a suitable monitoring technique so that the energy consumption could be minimised and the energy efficiency could be maximised.

Objective:

To devise a plan of action for achieving the above objectives.

Methodology:

The primary step for developing an effective energy management system is to collect the design energy consumption of each equipment of individual unit. Since each unit consumes different energy resource such as steam , power, fuel etc all the energy inputs are converted into kwhr or kcals/hr by using appropriate conversion factors.

Table 9.01 depicts a typical energy data equipment wise for each unit . Using bubble sorting program , the total quantity of energy consumed by each unit is evaluated and sorted in descending order.

The sorted information is given is **table 9.02** . From this it could be seen that Distillation unit consumes the maximum energy equivalent to 168.48 million kcal/hr followed by Visbreaker , Catalytic Cracking Unit and so on. This approach offers the *first level decision for energy management.*

A typical decision flow diagram for arriving at this is given in **fig 9.01**. A second level sorting may be carried out equipment wise using the same data. From this, class A items are identified by **Parato's method.** *(Ref 4,12,33).*

When once the individual energy consumption centres are identified by the sorting process , appropriate performance monitoring technique is selected for continuous monitoring. This could be by energy input / output models , EORT models are other routine efficiency calculations.

For example **Table 9.03** is the output of energy loss program which gives information such as current excess air and stack temperature of the heaters above norms and the energy loss figures in terms of fuel in tons / day as well as Rs/day. In the example given, it is found that the energy loss is found to be *33118.9 Rs/day* for the total system and the fuel equivalent of loss is *16.55945 tons / day.* **This is a cause for concern and needs immediate operational / maintenance action.**

Table 9.04 gives the routine information on excess air of the total heater / boiler system of the unit. From this info, operations manager may be able to rectify the operational parameters to achieve the target parameters very easily.

Table 9.05 gives the % energy loss due to poor insulation while **table 9.06** gives the moving average of the loss. **Fig 9.02** gives the lower limit and upper limit values determined statistically by the programme. So long as the losses are between lower limit and upper limit, the losses are treated as tolerable. Since this is basically a time dependent model, it is possible to predict the time at which the losses will reach the upper limit . This information is used for maintenance decision to minimise energy losses.

The major energy cost centre in the industry is the *fired heater / boiler system*.Their efficiency have to be monitored on a day to day basis, for which *heater / boiler efficiency* programs will have to be used. **Table 9.07** is the output of heater / boiler efficiency program *(12,14)* .

This follows indirect method to determine the efficiency and is based on **ABMA** *(American Boiler Manufacturers Association)* code. Data input for the program are fuel ultimate analysis, High heating value , ambient temperature , flue gas temperature , flue gas analysis , relative humidity , design heat duty , radiation and convection losses. This program gives the break-up of losses and heater / boiler efficiency on the basis of **HHV and LHV.**

In normal practice , quick estimate of boiler / heater efficiency is required by the operations staff to take corrective operational actions. **Table 9.08** is the output of the efficiency program from field data.

Fig 9.01. Decision Flow Diagram for Energy Management

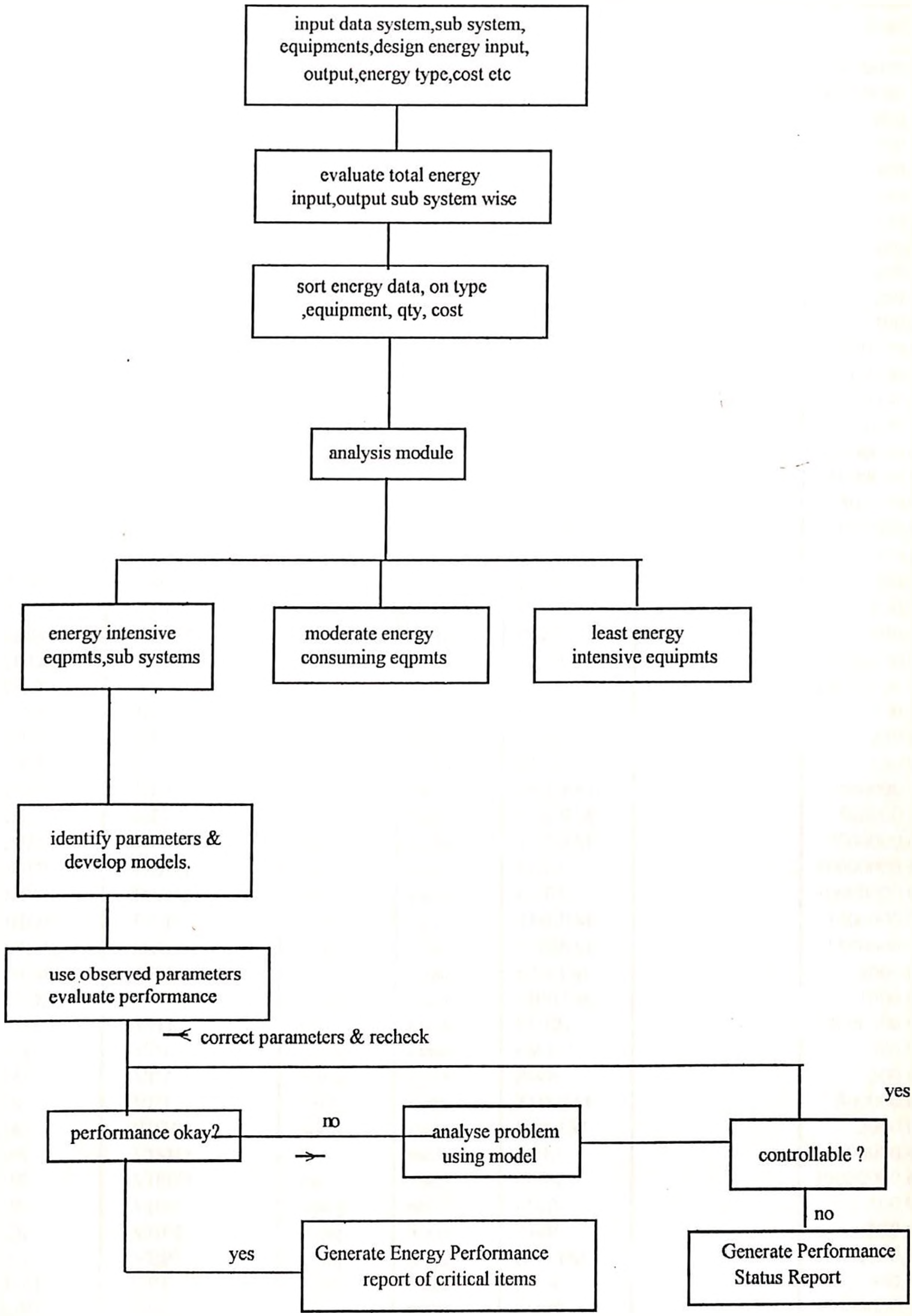


Table 9.01 Total Energy Data Base of a Refining Unit.

UNIT	EQUIPMENT	CODE	STATUS	ENRCONS	ENRGEN	ENRQTY
DIST	CH1	htr	main	FUEL		120000000.00
DIST	CH2	htr	main	FUEL		40000000.00
DIST	CP 1	pump	main	PWR		600.00
DIST	CP2	pump	main	PWR		500.00
DIST	CP3	pump	main	PWR		300.00
DIST	CP4	pump	main	PWR		300.00
DIST	CP5	pump	main	PWR		550.00
DIST	CP6	pump	main	PWR		300.00
DIST	CC1	compr	main	PWR		200.00
DIST	CC2	compr	stdby	PWR		250.00
DIST	CC3	compr	main	PWR		300.00
DIST	HE1	exch	main	THERM		1000000.00
DIST	HE2	exch	main	THERM		2000000.00
DIST	HE3	exch	main	THERM		2000000.00
DIST	DESALTR	static	main	PWR		1000.00
NHDS	NHD1	htr	main	FUEL		10000000.00
NHDS	NHRB1	exch	main	FUEL		5000000.00
NHDS	NHE1	exch	main	THERM		500000.00
NHDS	NHE2	exch	main	THERM		600000.00
NHDS	NP1	pump	main	PWR		300.00
NHDS	NP2	pump	main	PWR		200.00
NHDS	NCC1	compr	main	PWR		250.00
NHDS	NCC2	compr	stdby	PWR		300.00
KHDS	KHT1	htr	main	FUEL		15000000.00
KHDS	KHT2	htr	main	FUEL		10000000.00
KHDS	KP1	pump	main	PWR		300.00
KHDS	KP2	pump	main	PWR		250.00
KHDS	KP3	pump	main	PWR		150.00
KHDS	KE1	exch	main	THERM		500000.00
KHDS	KE2	exch	main	THERM		500000.00
KHDS	KE4	exch	main	THERM		2000000.00
DHDS	DDH1	htr	main	FUEL		40000000.00
DHDS	DDH2	htr	main	FUEL		10000000.00
DHDS	DE1	exch	main	THERM		1500000.00
DHDS	DE2	exch	main	THERM		1500000.00
DHDS	DR1	stmgen	main	HPSTM		2000.00
DHDS	DDH1	stmgen	main	MPSTM		1000.00
VAC	VH1	htr	main	FUEL		30000000.00
VAC	VP1	pump	main	PWR		500.00
VAC	VP2	pump	main	PWR		300.00
VAC	VE1	exch	main	THERM		500000.00
VAC	EJC1	static	main	HPSTM		2000.00
VIS	VISH1	htr	main	FUEL		60000000.00
VIS	VISH2	htr	main	FUEL		30000000.00
VIS	VBP1	pump	main	PWR		500.00
VIS	VBP2	pump	main	PWR		560.00
VIS	VBP3	pump	main	HPSTM		1000.00
SGP1	UP1	pump	main	PWR		300.00
SGP1	UH1	htr	main	FUEL		40000000.00
SGP1	UP2	pump	main	PWR		350.00

UNIT	*EQUIPMENT*	*CODE*	*STATUS*	*ENRCONS*	*ENRGEN*	*ENRQTY*
WHB1	WH1	htr	main	THERM		10000000.00
WHB1	WP1	pump	main	PWR		200.00
WHB1	WP2	stpump	main	HPSTM		4000.00
SGP2	UP2	pump	main	PWR		500.00
SGP2	UP2A	stpump	main	HPSTM		4000.00
SGP2	UH2	htr	main	FUEL		40000000.00
SGP2	UP2B	pump	main	PWR		150.00
WHB2	WH1	htr	main	THERM		20000000.00
WHB2	WP1	pump	main	PWR		250.00
WHB2	WPP2	pump	main	HPSTM		5000.00
SGP1	UB1	blr	stdby	PWR		.
SGP2	UB2	blr	stdby			.
SGP3	UB3	blr	stdby			.
SGP4	UB4	blr	stdby			.
SGP5	UB5	blr	stdby			.
SGP6	UB6	blr	stdby			.
SGP7	UB7	blr	stdby			.
SGP8	UB8	blr	stdby			.
CRU	CRP1	pump	main	PWR		200.00
CRU	CRH1	htr	main	FUEL		60000000.00
CRU	CRH2	htr	main	FUEL		20000000.00
CRU	CRP2	pump	main	PWR		150.00
CRU	CRP3	pump	main	PWR		120.00
ARU	AH1	htr	main	FUEL		15000000.00
ARU	AP1	pump	main	PWR		150.00
ARU	AP2	pump	main	PWR		150.00
PWR	PT1	turb	main	THERM		45000000.00
PWR	PT2	turb	main	THERM		45000000.00
PWR	PPT1	pump	main	PWR		150.00
PWR	PPT2	pump	main	PWR		150.00
CCRU	CCH1	htr	main	FUEL		40000000.00
CCRU	CCP1	pump	main	PWR		200.00
CCRU	CCP2	pump	main	PWR		200.00
CCRU	CCBL1	blr	main	HPSTM		30000.00
CCRU	CCC1	compr	main	HPSTM		40000.00
COK	COKP1	pump	main	PWR		250.00
COK	COKP1A	pump	stdby	PWR		250.00
COK	COKP1B	pump	main	PWR		250.00
COK	COKP2	pump	main	PWR		200.00
COK	COKP2A	pump	stdby	PWR		200.00
COK	COKP3	pump	main	PWR		150.00
COK	COKP3A	pump	stdby	PWR		150.00
COK	COKP4	pump	main	PWR		150.00
COK	COKP4A	pump	stdby	PWR		150.00
COK	COKP5	pump	main	PWR		180.00
COK	COKP5A	pump	stdby	PWR		180.00
COK	COKP6	pump	main	PWR		300.00
COK	COKP6A	pump	stdby	PWR		300.00
COK	COKP7	pump	main	PWR		500.00
COK	COKP7A	pump	stdby	PWR		500.00

UNIT	EQUIPMENT	CODE	STATUS	ENRCONS	ENRGEN	ENRQTY
COK	COKH1	htr	main	FUEL		18000000.00
COK	COKH2	htr	main	FUEL		18000000.00
BIT	BITP1	pump	main	PWR		120.00
BIT	BITP1A	pump	stdby	PWR		120.00
BIT	BITP2	pump	main	PWR		180.00
BIT	BITP2A	pump	stdby	PWR		180.00
BIT	BITBL1	blower	main	PWR		200.00
BIT	BITBL1A	blower	main	PWR		200.00
BIT	BITEJ1	static	main	MPSTM		2000.00
BIT	BITEJ2	static	main	MPSTM		2000.00

Table 9.02. Class A Units for Performanc Monitoring.

UNIT	STATUS	ENRDES	ENERGY
DIST	main	168483000.00	168.48
VIS	main	91631600.00	91.63
CCRU	main	90744000.00	90.74
PWR	main	90258000.00	90.26
CRU	main	80404200.00	80.40
DHDS	main	55120000.00	55.12
SGP2	main	43439000.00	43.44
SGP1	main	40559000.00	40.56
COK	main	37702800.00	37.70
VAC	main	32628000.00	32.63
KHDS	main	28602000.00	28.60
WHB2	main	23815000.00	23.82
NHDS	main	16745000.00	16.75
ARU	main	15258000.00	15.26
WHB1	main	13052000.00	13.05
BIT	main	3322000.00	3.32
SGP5	stdby	0.00	0.00
SGP3	stdby	0.00	0.00
SGP7	stdby	0.00	0.00
SGP8	stdby	0.00	0.00
SGP6	stdby	0.00	0.00
SGP4	stdby	0.00	0.00

Enrdes - kcal/hr
Energy - mmkcal/h

Table 9.03 Output of Heat Loss Program.

output file : *c:\enrmgm\tsi6.out*

a.Flue Gas Analysis & Fuel Consumption Details.

Date	Name of heater	%oxygen conv o/l	%oxygen conv i/l	target o2%	fuel cons t/hr
02.01.94	hhh1	5.95	3.25	3.00	5.855
02.01.94	hhh2	5.50	3.00	3.00	4.765
02.02.94	hhh3	6.55	4.50	3.00	3.976
02.02.94	hhh4	6.55	6.50	3.00	3.875
12.12.93	hhh5	6.50	4.15	3.00	5.675

b.Temperature Profile of the heaters/boilers

Date	Name of heater	ambient temp oC	flue gas temp oC
02.01.94	hhh1	25	350
02.01.94	hhh2	25	392
02.02.94	hhh3	25	320
02.02.94	hhh4	30	387
12.12.93	hhh5	20	329

c.Estimated Energy loss from heaters/furnaces due to air leaks & excess air

Date	name of heater	ENERGY LOSS WT% FUEL		TOTAL LOSS
		from leaks	excess air	tons/day
02.01.94	hhh1	2.570437	2.385738	3.611978
02.01.94	hhh2	2.400372	2.400372	2.745065
02.02.94	hhh3	2.932114	1.847119	2.797941
02.02.94	hhh4	3.566097	6.235075E-02	3.316470
12.12.93	hhh5	3.001464	2.15281	4.087995

Basis:
Energy loss/day is
equivalent to : 33118.9 Rs
Cost of fuel is Rs 2000 /ton.
Total Quantity of fuel
lost in tons/day is: 16.55945

********** end of program reached ***********

Table 9.04 Excess Air Monitoring Program Output

fuel Analysis %C	%H	%S	%O2	%EXC Air	VOL %O2	A/F RATIO
80.65	16.35	1.00	2.00	33.19	5.56	14.80
85.50	12.50	1.00	1.00	33.65	5.55	14.08
89.00	11.00	0.00	0.00	42.75	6.55	13.96
88.00	11.00	1.00	0.00	46.94	6.98	13.89
89.00	11.00	0.00	0.00	19.19	3.55	13.96
88.00	10.00	1.00	1.00	29.22	4.95	13.50
89.50	9.50	0.50	0.50	37.90	5.99	13.50
89.00	11.00	0.00	0.00	52.95	7.55	13.96
81.90	11.50	5.50	1.10	44.79	6.78	13.51
82.00	17.50	0.50	0.00	51.54	7.55	15.41
83.50	16.00	0.50	0.00	63.42	8.55	15.07
87.00	13.00	0.00	0.00	36.97	5.95	14.42
88.00	11.10	0.90	0.00	47.02	6.99	13.92
86.50	13.00	0.25	0.25	55.81	7.85	14.36

Note : This data may be useful for developing performance model for various types of heaters and user may evaluate the impact of fuel composition on theoritical Air / Fuel ratio, excess air % and impact of air flow on fuel effciency . When economics is the basic criteria , it is possible to determine the impact of fuel-mix on economics of operation. In this the cost of superior fuel mix is evaluated against the gain achieved in excess air reduction and higher efficiency.

Table 9.05 Heat Loss Analysis for HT Equipments

file name .... a:\loss2.out
No of observations 5

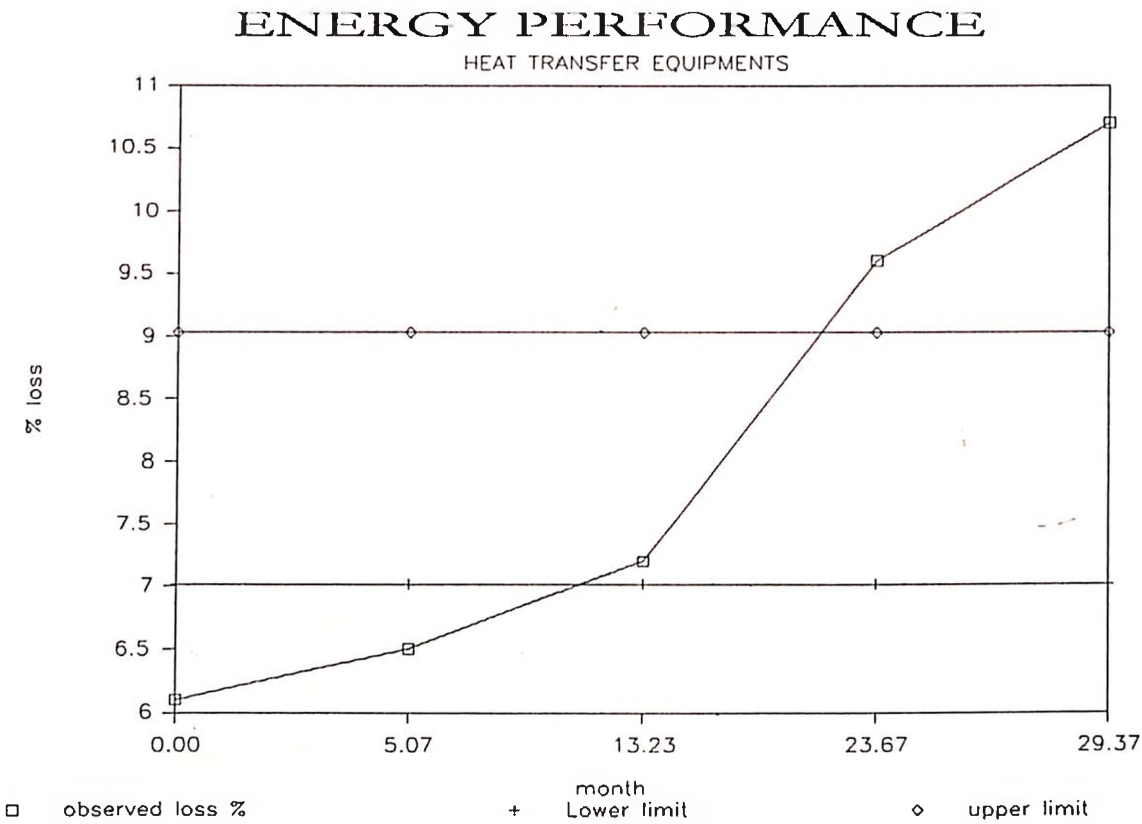
data no	% loss
1	6.1
2	6.5
3	7.2
4	9.6
5	10.7

Allowable / Norm value of loss 8.02 %
Standard Deviation of model 1.010817 %
Lower Control limit 7.009183
Upper Control limit 9.030816

Table 9.06 Energy Performance Fluctuations

data set no	observed % loss	moving avg %
1	6.1	0
2	6.5	0
3	7.2	6.3
4	9.6	6.85
5	10.7	8.40

Fig 9.02



Above figure 9.02 gives the % of energy loss due to poor insulation efficiency of the heater with the passage of time. After 12 months, energy loss started increasing above the stipulated lower limit and after 22.5 months, it started increasing above the upper limit. *From Energy management point of view, this is very poorly insulated* as even in the normal case the loss was 6% which is very high. ***Hence Energy managers may take a decision to modify the refractory lining from an economic analysis.***

Table 9.07 . OUTPUT - BOILER / HEATER EFFICIENCY

Equipment hhh1 Date 23 / 12 / 93

Fuel Data

Carbon	.865
Hydrogen	.125
Moisture	0
Oxygen	0
Sulfur	.010
Nitrogen	0

Boiler Duty mmkcal/h 82.5

Amb.Temperature oC 26.7 Flue Gas Temp oC 176.7

Relative Humidity 60 Excess Air 20

Fuel High Heating Value - Kcal/Kgm 11294.7

Fuel Low Heating Value - Kcal/kgm 10619.77

Boiler Efficiency & Losses

a.Dry Gas Loss	5.493384
b.Air Moisture loss	.1390107
c.Fuel Moisture Loss	6.42365
d.Radiation Loss	1.5
e.Unaccounted Loss	0

f.EFFICIENCY HHV basis *86.44395*

g.EFFICIENCY LHV basis *91.93784*

Table 9.08 BOILER / HEATER EFFICIENCY - FROM FIELD DATA

Equipment hhh2 Date 4 / 4 / 1994

Flue Gas Analysis

CO% by vol	0.0
O2% ,,	5.5
N2% ,,	83.7

Fuel Composition

Solid Fuel wt%	0
Liquid ,,	100
Gaseous ,,	0

Amb.Temperature oC	25
Flue Gas Temp oC	340

Excess Air 33.13892%

Fuel High Heating Value - Kcal/Kgm	10900
Fuel Low Heating Value - Kcal/kgm	10200
Flue Gas Kg/Kg fuel	20.46078

Boiler Efficiency & Losses %

a.Flue Gas Loss	*15.16505*
b.Other Losses	*1.45*
c.EFFICIENCY HHV basis	*78.02995*
d.EFFICIENCY LHV basis	*83.38495*

Efficiency monitoring
(pumps / compressors / turbines)

Rotating equipment efficiency is very important from the point of view of energy consumption. In case of pumps , compressors , turbines etc actual performance at any point of time is determined by the actual energy consumed against the base case , which is normally represented by the characteristic curves.This process has to be repeated for all the equipments more frequently for minimising the energy consumption . Since this is a very routine and tedious activity , Interpolation models are found to offer an effective solution .

Programs *Pump* ,*Turbine* , *Compress* may be used to monitor the efficiency of Energy intensive equipments like pumps, compressors, turbines etc from their *basic characteristic curve data.* Above data is stored in respective files and observed operating parameters are entered in the monitoring program.

The program automatically evaluates the performance w.r.t the base data and gives the deviation as % from the base data . *If this deviation is found to be higher than the upper control limits, the situation warrants investigation.* This eliminates the tedious job of searching the characteristic curve data for each equipment , identifying the base value for the observed conditions and estimating the deviation for number of equipments.

A typical output for monitoring the performance of a Centrifugal Pump is given in **table 9.09.** (provision exists for entering the data from console also). From the data , it may be observed that at higher flow rates, head developed starts drooping down against the base case. This needs an investigation from mechanical side.

The probable reasons could be

* Damaged impeller
* Clogged wanes
* Damaged / eroded casing
* Increase in the gap between casing wear rings and impeller due to erosion etc.

It is very interesting to note that systematic data analysis of this type not only improves the energy efficiency of the system , but also improves the quality of maintenance and longer life of rotating equipments .

Table 9.09. input data for the pump efficiency program ......

flow rate m3/hr	Head dev kg/cm2
0	25.00
20	22.55
40	21.00
60	20.00
80	19.55
100	19.00
120	18.50
140	18.10

interpolated values for observed conditions...........

new value of x.... 90
interpolated value of head... 19.30952
observed value of head 18.5
% deviation 4.19

new value of x.... 105
interpolated value of head... 18.8378
observed value of head 17.65
% deviation 6.31

new value of x.... 115
interpolated value of head... 18.57447
observed value of head 17
% deviation 8.48

new value of x.... 130
interpolated value of head... 18.43843
observed value of head 16.55
% deviation 10.24

Modelling is a very powerful route that may be used for identifying *the fouling tendency of heat transfer equipments such as heat exchangers, coolers, condensers etc.* It is possible to predict the heat transfer rate from the fouling rates observed on two occasions only. This is a very simple technique that involves observed temperature readings on two occasions for the hot & cold streams. The program *fouling* estimates the fouling rate from these readings and estimates future values from the observed data. Typical output for an exchanger is given in **table 9.10**. *This is a very useful program for industrial applications from field data and does not involve any rigorous heat transfer calculations which is an added advantage* . This is based on the equation

$$R_1 = R_0 * (1 - \exp^{-A*t_1}) \quad \& \quad R_2 = R_0 * (1 - \exp^{A*t_2})$$

(where Ro is the base resistance at time t0 and R1 and R2 are observed resistances at time t1 and t2 hrs respectively from the base time in hrs)

Table 9.10. Estimation of Fouling Rates in Heat Tranfer Equipments (from field data)

Observed Resistance 1	.007	units
Time	50	hrs
Observed Resistance 2	.01	units
Time	75	hrs

Exponent for scaling function	4.076499E-03
Base Resistance from program	3.796201E-02

Anticipated fouling resistance and transfer coefft

time (hrs)	resistance	h.t.coefft kcal/hr/m2/oC
80	1.056412E-02	94.66003
120	0.0146864	68.09020
160	1.818844E-02	54.97997
200	2.116357E-02	47.25101
250	2.426112E-02	41.21822

(h.t.coefft = 1 / resistance)

Table 9.11 gives the output of the models simulated from the above data which could be used for predicting the resistance due to fouling at any point of time. *(63)*

Table 9.11 Fouling Resistance Model

file name : c:\enrmgm\scmodel
base value for X variable : 80

X values hours	Y values coefft
80	94.6600
120	68.0900
160	55.0000
200	47.2500
250	41.2500
300	37.3300
350	34.6700
400	32.7600

Heat Exchanger Scaling Model

hours	X1	ACTUAL h.t.coefft	ESTIMATED h.t.coefft
80	0.0000	94.6600	76.7779
120	40.0000	68.0900	70.1152
160	80.0000	55.0000	63.4524
200	120.0000	47.2500	56.7897
250	170.0000	41.2500	48.4613
300	220.0000	37.3300	40.1329
350	270.0000	34.6700	31.8045
400	320.0000	32.7600	23.4761

STANDARD ERROR OF ESTIMATE IS : 8.9483

B.Exponential Model

hours	X1	ACTUAL h.t.coefft	ESTIMATED h.t.coefft
80	0.0000	94.6600	77.1658
120	40.0000	68.0900	68.2177
160	80.0000	55.0000	60.3071
200	120.0000	47.2500	53.3139
250	170.0000	41.2500	45.7015
300	220.0000	37.3300	39.1760

350	270.0000	34.6700	33.5823
400	320.0000	32.7600	28.7873

STANDARD ERROR OF ESTIMATE : 7.1693

C.Non-Linear Model

hours	X1	ACTUAL h.t.coefft	ESTIMATED h.t.coefft
80	0.0000	94.6600	89.0573
120	40.0000	68.0900	72.7957
160	80.0000	55.0000	59.2860
200	120.0000	47.2500	48.5284
250	170.0000	41.2500	38.9513
300	220.0000	37.3300	33.6742
350	270.0000	34.6700	32.6971
400	320.0000	32.7600	36.0201

STANDARD ERROR OF ESTIMATE : 3.6522

D.Polynomial Model

hours	X1	ACTUAL h.t.coefft	ESTIMATED h.t.coefft
80	0.0000	94.6600	93.3095
120	40.0000	68.0900	70.5718
160	80.0000	55.0000	55.2941
200	120.0000	47.2500	45.8992
250	170.0000	41.2500	40.0257
300	220.0000	37.3300	37.7997
350	270.0000	34.6700	36.1409
400	320.0000	32.7600	31.9692

STANDARD ERROR OF ESTIMATE : 1.3418

Out of the above 4 models, *polynomial model* has been observed to be the most appropriate one as the standard error of estimate is the minimum. The scaling tendency or heat transfer coefft observed & model value is as shown in the figure overleaf. *These models may be used to determine the optimum cleaning time of heat transfer equipments for increasing the transfer efficiency and minimising losses & energy cost.* For industries, having a number of such equipments, this must be monitored continuously lest the plant efficiency is likely to droop down. For arriving at the optimum cleaning time, the mean value & standard deviations are estimated for a full cycle and the control limits are set for monitoring (**UCL,LCL**). From the profile, the cleaning time is estimated by calculating *cleaning cost vs energy cost.* **Fig 9.03** *shows the fouling tendency and how the exchanger behaves w.r.t time.* **Table 9.12** *and* **Table 9.13** *show the output of moving average program for heat transfer coefficient to decide heat exchanger cleaning time.*

Fig 9.03 H.T.EQUIPMENT PERFORMANCE

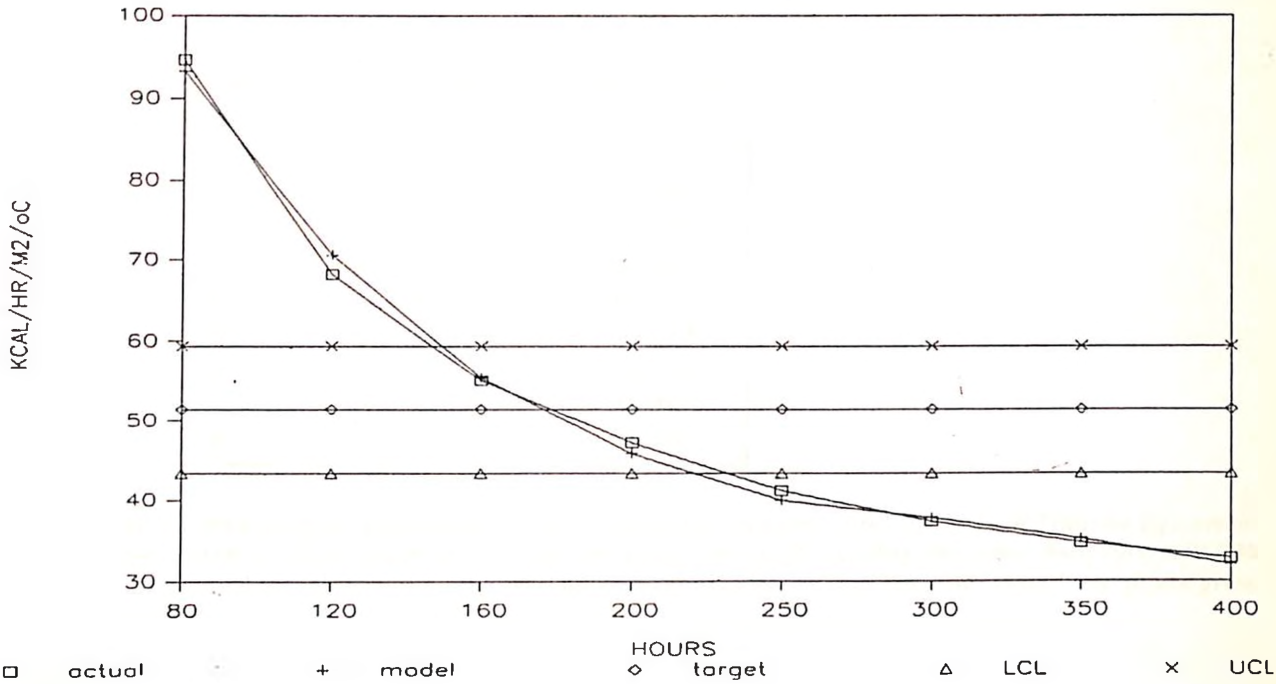


Table 9.12 Heat Transfer Equipment Performance Analysis

file name .... c:\enrmgm\lclucl
No of observations 8

data no	h.t.coefft
1	94.66
2	68.09
3	55.00
4	47.25
5	41.25
6	37.33
7	34.67
8	32.76

Target value of h.t.coefft 51.37625 units
Standard Deviation of model 7.964836
Lower Control limit 43.41142
Upper Control limit 59.34109

Table 9.13. H.T.Equipment Performance Fluctuations

data set no	observed h.t.coefft	moving avg
1	94.66	0.000
2	68.09	0.000
3	55.00	81.375
4	47.25	61.545
5	41.25	51.125
6	37.33	44.250
7	34.67	39.290
8	32.76	36.000

Note: It may be noted from the performance analysis data that cleaning of the above Heat Transfer Equipment must be undertaken by 260th day as the moving average of the coefft reaches the lower limit value of 51.38 units. Any postponement of cleaning will only lead to energy loss as indicated above and the figure given in previous page.

Table 9.14. INPUT DATA

flow nm3/h	rpm	press ata	power kwh
70000	5355	5.00	5700
70000	5610	5.70	6400
75000	5355	4.95	6100
75000	5610	5.60	6700
75000	5891	6.40	7600
80000	5355	4.90	6300
80000	5610	5.45	7000
80000	5891	6.30	8000
85000	5355	4.75	6500
85000	5610	5.30	7300
85000	5891	6.15	8300
90000	5355	4.60	6600
90000	5610	5.10	7500
90000	5891	5.95	8700
95000	5355	3.80	6700
95000	5610	4.80	7700
95000	5891	5.80	8900
100000	5355	3.20	6750
100000	5610	4.55	7800
100000	5891	5.50	9000
105000	5610	3.90	7900
105000	5891	5.25	9100

Performance of compressors could be monitored by models. The input data is entered into an input file and the program is run using this data. Two models are developed for the same data (Multi variable linear & non-linear). The model that gives less standard error of estimate is taken as a valid model. In this particular case the objective is to determine the performance of turbine as well as the compressor. The output of turbine is measured by it's steam consumption for specific gas flow,rpm & pressure developed while the performance of compressor is determined by gas flow and rpm which is reflected in the polytropic head developed. Other variables such as gas molecular weight,steam quality,suction pressure etc are assumed constant.It is possible to incorporate these variables also in the model. ***This model is useful for process as well as maintenance decisions.*** The input data is given in **table 9.14** while program output of performance models are given in **tables 9.15**, **9.16** and **fig 9.04**.

Table 9.15 . Model for testing Compressor Turbine

No of data sets used in the model : 22
Independant variables used in the model : 3

Variables used in the model are ......

variable 1 is flow
variable 2 is rpm
variable 3 is press
variable 4 is power kw

NON LINEAR MODEL OUTPUT - Turbine Performance

observed value power	calculated by Sci.Model	error term
5699.998	5738.24756	-38.25002
6100.002	5991.52393	108.47852
6300.002	6237.79688	62.20567
6499.999	6455.61182	44.38672
6599.998	6664.90674	-64.90868
6700.002	6691.28564	8.71616
6750.001	6726.73193	23.26927
6400.000	6480.75488	-80.75426
6700.002	6758.36816	-58.36635
7000.000	7016.66162	-16.66237
7300.002	7265.44189	34.55997
7499.998	7493.19873	6.79900
7700.000	7684.71875	15.28089
7799.998	7876.11523	-76.11685
7900.000	7927.84131	-27.84197
5699.998	5738.24756	-38.25002
6100.002	5991.52393	108.47852
6300.002	6237.79688	62.20567
6499.999	6455.61182	44.38672
6599.998	6664.90674	-64.90868
6700.002	6691.28564	8.71616
6750.001	6726.73193	23.26927
6400.000	6480.75488	-80.75426
6700.002	6758.36816	-58.36635
7000.000	7016.66162	-16.66237
7300.002	7265.44189	34.55997

7499.998	7493.19873	6.79900
7700.000	7684.71875	15.28089
7799.998	7876.11523	-76.11685
7900.000	7927.84131	-27.84197
7600.000	7674.84619	-74.84582
8000.001	7983.02832	16.97263
8299.999	8271.21289	28.78612
8700.000	8538.01855	161.98141
8899.997	8806.54102	93.45620
8999.997	9026.44629	-26.44888
9100.000	9246.72559	-146.72505

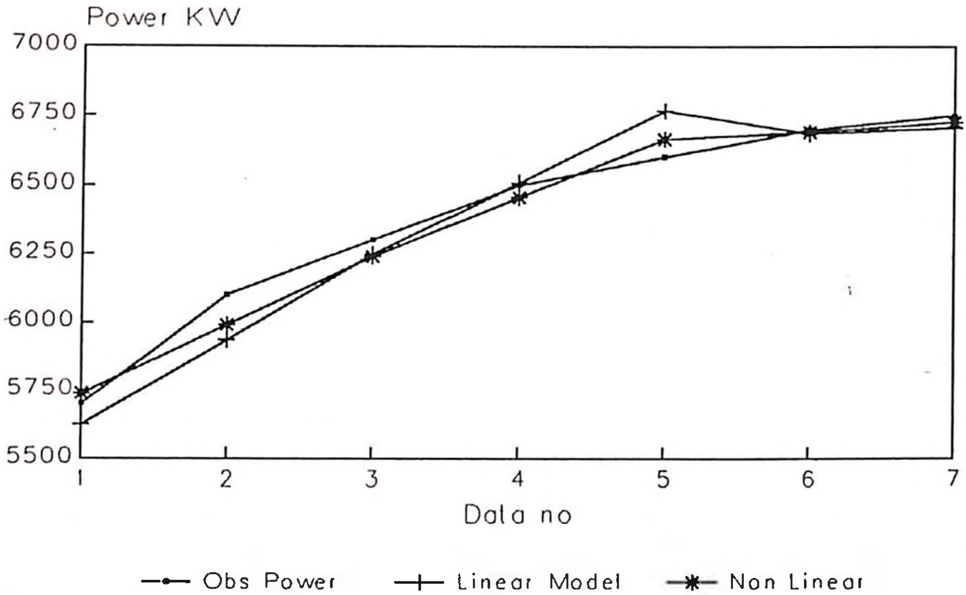
Standard Error of the estimate = 71.06937

Table 9.16 . Linear Model Output - Turbine

observed power	simulated value	error term
5700.00000	5623.18848	76.81152
6100.00000	5935.76660	164.23340
6300.00000	6248.34277	51.65723
6500.00000	6508.26465	-8.26465
6600.00000	6768.18848	-168.18848
6700.00000	6685.86035	14.13965
6750.00000	6708.83887	41.16113
6400.00000	6484.46191	-84.46191
6700.00000	6770.71191	-70.71191
7000.00000	7030.63574	-30.63574
7300.00000	7290.55957	9.44043
7500.00000	7524.15527	-24.15527
7700.00000	7705.09473	-5.09473
7800.00000	7912.36426	-112.36426
7900.00000	7909.01660	-9.01660
7600.00000	7734.87598	-134.87598
8000.00000	8021.12598	-21.12598
8300.00000	8281.04785	18.95215
8700.00000	8514.64355	185.35645
8900.00000	8774.56543	125.43457
9000.00000	8955.50684	44.49316
9100.00000	9162.77637	-62.77637

Standard Error of the estimate = 89.25016

Fig 9.04. SIMULATED MODEL OUTPUT
(Turbine Performance Monitoring)



Note: Above figure is based on the simulated output for a certain set of readings given in **table 9.14,9.15 and 9.16.**

Table 9.17 is the consolidated report of heater efficiency of a heater named *testhtr* for a period of **six** months.

From the efficiency data , it is possible to predict the probable efficiency at a future period with reasonable accuracy, if the same parameters are maintained and the same efficiency trend continues. **Table 9.18** gives the calculation for increase in the operating cost of the heater due to lower efficiency, compared to the base case conditions.

Since the break-up of energy losses are available for each observation period, it is possible to develop efficiency and loss models as given in **fig 9.05 and 9.06.**(*7,8,13,18,30,36*).

Predicted efficiency and increase in energy costs due to efficiency deterioration for futuristic period is given in **table 9.19.** This could be used for economic analysis of operation to take equipment replacement / maintenance decisions to optimise the operation.

Program Output

Table 9.17. RESULTS - BOILER / HEATER EFFICIENCY

User : Abad Refineries SA Ltd
Equipment : testhtr

Date	1.1.94	1.2.94	1.3.94	1.4.94	1.5.94	1.6.94
Stream day	10	41	69	100	130	161
I.Fuel Data:						
Carbon	.79825	.79825	.80300	.80775	.81250	.81725
Hydrogen	.18175	.18175	.17700	.17225	.16750	.16275
Moisture	.00175	.00175	.00200	.00225	.00250	.00275
Oxygen	.00325	.00325	.00300	.00275	.00250	.00225
Sulfur	.01175	.01175	.01200	.01225	.01250	.01275
Nitrogen	.00325	.00325	.00300	.00275	.00250	.00225
Ash	.00000	.00000	.00000	.00000	.00000	.00000
II.Observed Process parameters						
Boiler Duty mmkcal/h	60.0000	60.0000	60.0000	60.0000	60.0000	60.0000
Fired Duty mmkcal/h	61.8000	61.9500	62.5000	62.7500	62.7500	62.7000
% Load on Design Duty	103.0000	103.2500	104.1667	104.5833	104.5833	104.5000
% Unburnt matter in refuse	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Amb.Temperature oC	28	28	30	29	29	29
Flue Gas Temp oC	185	191	215	245	245	265
Relative Humidity	81.0	81.0	80.0	79.5	79.0	80.0
Excess Air	12.3671	15.2527	18.3359	19.6432	21.6501	26.9459
Fuel High Heating Value *	11497.5	11497.5	11440.0	11382.5	11325.0	11267.5
Fuel Low Heating Value *	10514.9	10514.9	10482.9	10450.9	10418.9	10386.9

* kcal/kgm

III.Energy Losses						
a.Dry Gas Loss :	5.5924	5.9580	6.9620	8.2115	8.3518	9.5296
b.Air Moisture loss :	0.2138	0.2276	0.2959	0.3257	0.3284	0.3786
c.Combustion Moisture Loss :	9.5637	9.6029	9.5399	9.5250	9.3094	9.2111
d.Fuel Moisture Loss :	0.0102	0.0103	0.0120	0.0138	0.0154	0.0173
e.Radiation Loss :	1.5000	1.7500	2.1500	2.2700	3.1500	3.990
f.Unaccounted Loss :	0.0000	0.0000	0.0500	0.2600	0.4500	0.7800
g.Loss due to combustibles :	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total Loss % (dry basis) (less (b))	16.6663	17.3213	18.7138	20.2803	21.2766	23.5281
IV.Boiler/Heater Efficiency						
a.EFFICIENCY HHV basis :	83.3337	82.6787	81.2862	79.7197	78.7234	76.4719
b.EFFICIENCY LHV basis :	91.1205	90.4043	88.7071	86.8254	85.5693	82.9548

NOTE:

a.Air misture loss is due to moisture present in combustion air.
b.Combustion moisture is due to combustion of H2 in fuel to water.
c.Fuel moisture is due to presence of water in the fuel fired.
d.Radiation loss is due to heat loss from the exposed boiler surface.
e.Calorific Value of combustibles in refuse is taken as 7800 BTU/Lb.

*** end of heater efficiency program ***

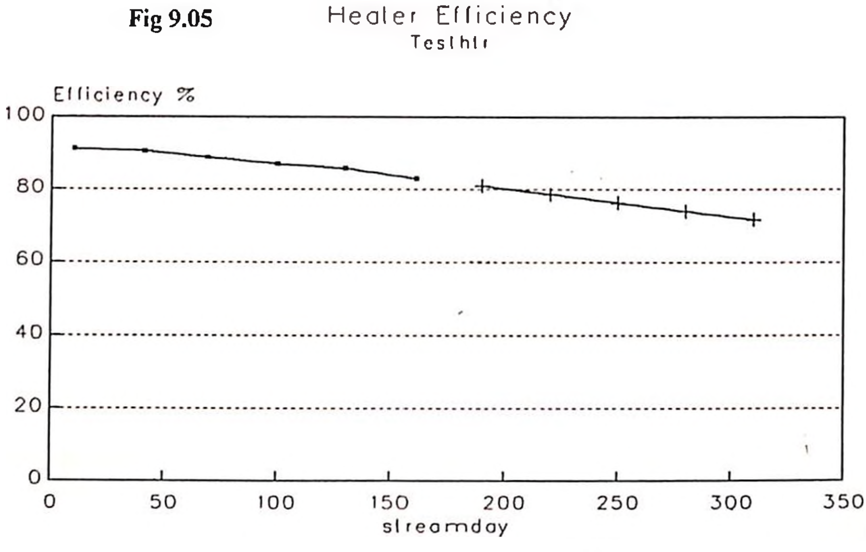
Table 9.18

item	Observed Heater Efficiency Data for Testhtr					
a.Stream day	10	41	69	100	130	161
b.Efficiency %(on LHV)	91.1205	90.4043	88.7071	86.8254	85.5693	82.9548
c.Fired duty mmkcal/h	61.8000	61.9500	62.5000	62.7500	62.7500	62.7000
d.Absorbed duty for (same heat load)	56.3125	56.0055	55.4419	54.4829	53.6947	52.0127
e.Equivalent fired duty	61.8000	62.2896	63.4813	64.8571	65.8092	67.8833
f.Excess fired duty required over base (mmkcal/h)	0.0000	0.4896	1.6813	3.0571	4.0092	6.0833
g.Eqvt fuel in tons/month (CV=10450 kcal/kgm)		33.731	115.843	210.634	276.231	419.136
i.Increase in operating cost Rs/month (@ Rs 2000/mt		67464	231688	421269	552462	838274

Assumptions:

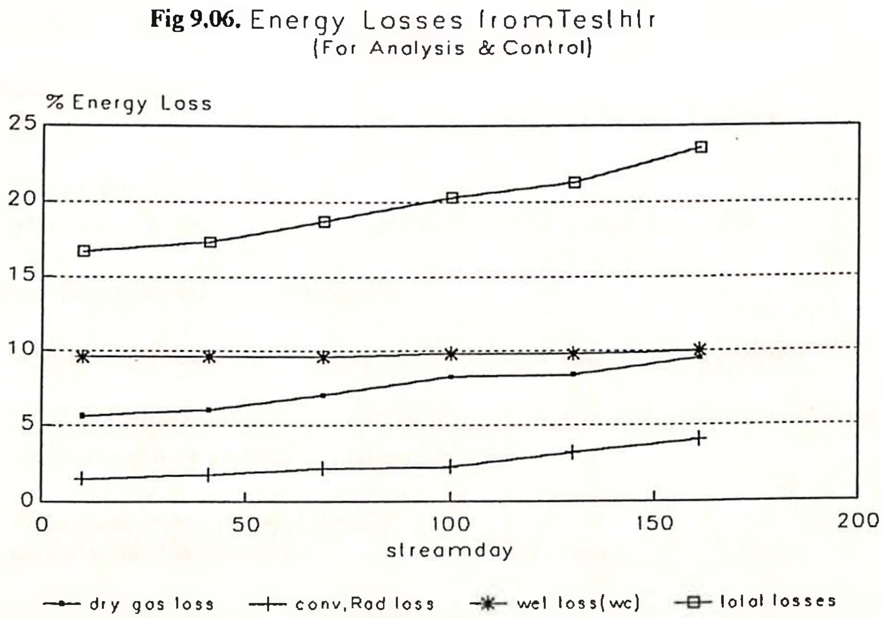
1.Efficiency of heater follows the same trend unless theactual problem is identified & solved in time.
2.Heater Operating Data is available for performance evaluation
3.Coil inlet/outlet temperatures & feed quality remain constant.
4.Feed Rate is adjusted consistent with the efficiency.

Fig 9.05



Evaluated by Techno Therm (based on actual heater performance)

Fig 9.06.



Ref:- Techno Thermoutput

Note: out of the above losses dry gas loss & convection / Radiation losses are controlled by excess air,air leakage,refractory conditioning etc while wet loss is controlled by fuel mix.

Table 9.19

item	Predicted efficiency by Models				
	*	*	*	*	*
Stream day	190	220	250	280	310
efficiency % (on LHV)	80.913	78.606	76.265	73.937	71.674
fired duty mmkcal/h	63.000	63.000	63.000	63.000	63.000
absorbed duty for (same heat load)	50.975	49.522	48.047	46.580	45.154
equivalent fired duty	69.596	71.638	73.838	76.163	78.568
excess fired duty required over base (mmkcal/h)	7.796	9.838	12.038	14.363	16.768
eqvt fuel/m in tons	537.162	677.863	829.431	989.537	1155.287
cost of excess fuel in Rs @ Rs 2000/mt	1074323	1355725	1658861	1979174	2310573
increase in operating cost Rs/month :	1074324	1355726	1658862	1979175	2310574
marginal savings : Rs/month(w.r.t June)	236050	281402	303136	320313	331399
Average Saving/month	294460 Rs				

* Efficiency of heater predicted by models for the same operating trend .

Modelling could identify abrupt increase in heat losses from convection/radiation surfaces and also air leaks in convection section.

Average monthly savings achieved due to Modelling technique   Rs 294460

Table 9.19 gives the output of system analysis program to determine the energy consumption cost of class A equipment.

Conclusion:

In this chapter it had been shown how computer aided energy management and models could be used for improving the productivity of the industry by systematic recording , analysing and developing and applying the performance parameters.

When once the performance statistics are developed, the same could be used to monitor the peformance of the entire system . In advanced control systems, these parameters are used to control the operating parameters by suitable analog interface.

In modern processes, a centralised energy monitoring console is incorporated, which continuously monitors the energy efficiency of the system using the above models `and sends control signals to the process module. A typical example is the auto damper control which closes or opens the damper by a hydraulic operated mechanism to control excess air . *This in turn is cascaded to fuel flow to control the fuel consumption.*

Equipment replacement / maintenance decisions could also be taken with the help of these data. (e.g. tube cleaning / replacement)

Since energy costs constitute nearly 70% of total cost, energy data must be monitored more closely by every one , for which the computer-aided system is of immense use.

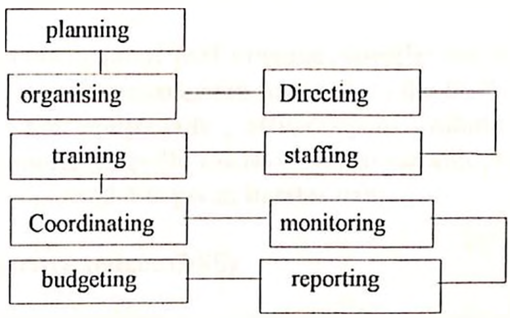
Environmental Management Models

Chapter 10.Environmental Management Models

While process industries play a major role in the economic growth rate and productivity , environmental problems associated with them cannot be under estimated. *Refering to fig 1.01 in Chapter 1 (factors affecting industrial performance)* , it may be noted that all industries are governed by Government regulations such as EPA,CAA, WA,HWA etc which will have to be complied with by all industries, however profitable they may be . Many environmental hazards remain latent and unnoticed unless a serious problem arises and affects the surrounding community. Uncontrolled industrial pollution had led to loss of lives, flora and fauna. Even loss of certain species of birds and animals have been repored by environmental scientists . Environmental Management of process industries is indispensable as these are not only the creators of wealth , but also the creators of environmental hazard and pollution norms of all kinds will have to be complied with for the very survival of the industry itself. When the complexity of the process industry is high , the emissions and discharges of toxic chemicals go up and cost of treatment also tends to be high . Computer aided Environmental Management may be used to control emissions, ambient air quality, effluent quality discharged and solid wastes very systematically . *(Ref 23,24,33,64)*

A.Environmental Management: Activities related to Environmental Management are given in *fig10.01* below.

fig 10.01. Environmental Management Activities.



b.Planning: Environmental Planning mechanism involves deciding in advance

* what shall be the size of the pollution handling process
* what shall be the type of pollutants for the proposed configuration
* how they may be handled
* what alternates are available for combating pollution
* which is the best economical measure
* what happens if the processing capacity is enhanced / process configuration changed
* what will be the effect of feed mix
* what shall be the impact of operating severity
* what will be the impact to the environment if a disaster occurs and how this could be tackled effectively etc.

This is applicable for an on-going process also to control pollution at minimum cost and meet all the stipulated standards and fulfill social obligations without any dispute / litigation.

This section deals computer application programs for monitoring various types of pollution levels of the example **ABC Refineries Ltd** covered in earlier chapters.-These programs may be used for taking appropriate pollution control decisions at the right time and cost as the industry has to fulfill the mandatory pollution norms .

c.Air Pollution control model :

Normal Emissions from the stacks of heaters, boilers, emergency vents , safety release systems, etc used in the process are CO2 , CO, NOx, SO2, H2S, NH3, Hydro Carbons and Suspended Particulate Matter which depend on the process configuration employed for maunufacturing the required product. Total quantum of these pollutants released from the process could be established by a conventional material balance

A typical program output to determine SO2 ,NOx, SPM emission levels from various sections of a unit based on actual analysis is given in **table 10.01** . This program gives information such as whether pollution level from all equipments are within the stipulated limit or not. **Table 10.01a** represents a typical flue gas analysis for a process unit comprising of various process heaters and boilers. This gives emission details such as SO2 and SPM .**Fig 10.02 and 10.03** give the emission levels of each heater / boiler to diagnose the behaviour of each fired equipment. It may be noted that all emissions are within stipulated limits and represents good operation.This is because of a cleaner fuel mix used in the unit comprising of Low Sulfur Heavy Stock and Desulfurised fuel gas. Impact of type of fuel used on fugitive emissions may be estimated by material balance.

For assessing environmental management performance , specific emission rate from each unit may be used. Quantity of pollutants emitted to the atmosphere depends on the feed rate, feed quality, fuel fired ,quality of fuel used , efficiency of the equipments , efficiency of pollution control devices etc. For understanding the impact of these parameters on pollution level , multi variable pollution models may be used .A typical output using the mv non linear model is given in **table 10.02.**

d.Identifying pollution centre for corrective action: (DSS)

Identifying pollution centre and taking corrective action is very important for sustaining a cleaner environment.Two important aspects of air pollution are

1.Emission of pollutants in kg or t/hr
2.Specific emission rate in kg of pollutant/ton feed processed.

These two parameters are very important to measure the environmental impact due to industrialisation such as the addition of more process units or capacity expansion.

emission
rate kg/hr = feed processed / unit x specific emission rate x no of units in the area

It may be seen from the above logical relationship, that pollution rate increases with quantity of feed processed / unit (i.e.capacity expansion) , specific emission rate (type of fuel,fuel mix,performance of emission control system) and the rate of industrialisation.This explains why industrial belts are prone to more air pollution than normal suburburn / rural sections.

e. Impact of fuel mix on Air Pollution:

One of the ways of controlling air pollution is by adopting a cleaner fuel mix . If the fuel used in the fired equipment like heater / boiler has high ash content and sulfur, both SPM and SO2 emissions will tend to rise . Excess air and Nitrogen in the fuel further adds to NOx emissions also. To reduce these pollutions certain modern treatment processes such as DeNOx ,DeSOx are available.For SPM control, techniques such as Electro Static Precipitators / Bag filters are incorporated in the flue gas outlet before it is vented to the atmosphere. Certain alkaline additives are also added to the flue to control NOx & SO2.Low NOx burners are also used in industrial practice to control NOx emissions.Fuel mix effect on air pollution may be easily identified by theoritical models based on the stoicheometric relationship which is given in the **tables 10.03 and 10.04**.Though these models consider only 3 types of fuels used in a process industry, provision exists to consider any number of fuels . Two multi variable models have been developed by the program and they are given by

Suspended Particulate Matter:

$$\text{spm kg/h} = 8.09593 * \text{fuel rate} + 1.96965 * \%a + 2.20512 * \%b + 1.61256 * \%c - 200.31056 \quad (1)$$

$$\text{spm kg/h} = .2093887 * (\text{fuel})^{0.97948} * (\%a)^{0.31165} * (\%b)^{0.68219} * (\%c)^{0.00082} \quad (2)$$

Standard Error of Model 1 = 0.34874

Standard Error of model 2 = 0.20971

Sulfur-di-Oxide Emission:

$$SO2 \text{ kg/h} = 67.41148 * \text{fuel rate} + 4.04556 * \% a + 2.50810 * \%b + 6.37297 * \%c - 382.68945 \quad (3)$$

$$SO2 \text{ kg/h} = 92.10649 * (\text{fuel})^{1.01627} * (\%a)^{-0.03196} * (\%b)^{-0.16416} * (\%c)^{0.13805} \quad (4)$$

Standard Error of Model 3 = 2.27393

Standard Error of model 4 = 5.85711

Similar models could be used for other types of emissions also with reasonable accuracy. Program output clearly indicates model output value against observed emissions and these models could be used for estimating emission levels with different fuel mix. It is possible to carry out optimisation of fuel mix for the entire spectrum of industries using this type of modelling methodology.

f. Determining Effectiveness of Pollution Control Technologies:

Modelling technique may be used for identifying the impact of Pollution Control measures on ambient air quality / atmospheric pollution at micro level. For example if we consider the case of a coal fired power boiler, variables affecting the pollution rate are load factor, boiler efficiency, turbine efficiency, s% in coal, ash % , efficiency of electro static precipitator etc as pollution rate is governed by the combination of these parameters.Hence from a systematic data analysis, it is possible to determine the impact of the pollution control device on pollution rate and carry out an economic analysis.(**Ref Table 10.05**)

Similar exercise could be carried out for fuel desulfurisation where the variables considered are the rate of consumption, %S, %soot, combustion efficiency ,air/fuel ratio etc vs pollution level. These models find extensive application in economic analysis of pollution control measures such as selection of alternates or alternate technologies, feed mix selection etc.

g. Trouble Shooting Applications :

Modelling may be used for trouble shooting operating problems. Typical example is the SPM emission from stacks. Analysis of SPM particulates may be used to identify whether the particulates are from the *fuel or refractory or from metal walls , Soot etc.* If the rate of emission is higher than what has been predicted by the model, the reason could be due to refractory damage which needs an investigation of the system. While presence of soot indicates loss of fuel, presence of iron oxide indicates corrosion of the wall section and/or heating coils used in the system .It is possible to know the deterioration of coils from the analysis and the rate of emission.

h. Conclusion:

Mathematical models are gaining importance and are used as an **effective management tool** in view of the complexity of the problems faced by various types of industries, technologies used and population growth. When once the model parameters are incorporated into the system , the executive will get the pollution levels for the entire system and gets the information on non-compliance of any equipment for remedial action.

Table 10.01. Specific Emission Levels

FEED	*SPM kg/h*	*SO kg/h*	*SP_SPM*	*SP_SO2*
21.0	1.5726	7.7276	0.00007	0.00037
20.5	1.4603	8.8625	0.00007	0.00043
20.6	1.4828	24.2867	0.00007	0.00118
16.0	0.7676	13.1020	0.00005	0.00082
29.5	3.4598	11.5724	0.00012	0.00039
24.3	2.9580	19.1253	0.00012	0.00079
20.1	1.8722	30.4713	0.00009	0.00152
25.4	2.3515	41.1505	0.00009	0.00162
26.0	1.9209	33.2838	0.00007	0.00128
40.0	3.2389	13.6256	0.00008	0.00034
41.0	3.3549	25.3356	0.00008	0.00062
52.0	6.3654	89.1157	0.00012	0.00171
40.5	3.3924	44.5689	0.00008	0.00110
47.0	3.8192	51.5598	0.00008	0.00110
585.0	4.8714	68.4517	0.00001	0.00012
580.0	3.9316	75.7167	0.00001	0.00013
587.0	4.7329	79.9691	0.00001	0.00014
210.0	3.6320	24.2344	0.00002	0.00012
215.0	3.6882	27.2163	0.00002	0.00013
220.0	3.0853	53.9936	0.00001	0.00025
225.0	3.3699	40.9039	0.00001	0.00018
227.0	3.3287	39.8874	0.00001	0.00018
150.0	1.2806	10.1121	0.00001	0.00007
145.0	1.3105	8.3151	0.00001	0.00006
152.0	1.6063	20.2453	0.00001	0.00013
142.0	1.7486	6.0297	0.00001	0.00004
138.0	1.3105	22.2111	0.00001	0.00016
300.0	8.7318	126.6117	0.00003	0.00042
312.0	8.8367	73.1312	0.00003	0.00023
285.0	8.1253	125.1009	0.00003	0.00044
289.0	14.8277	246.7014	0.00005	0.00085
265.0	8.0279	123.8788	0.00003	0.00047
100.0	1.4004	10.3339	0.00001	0.00010
115.0	1.4041	15.9781	0.00001	0.00014
112.0	1.4004	23.3720	0.00001	0.00021

(Ref 37,38,39)

Input Details of Multi Variable Linear Model.

a.Title: Fuel Mix effect on emission of SPM
b.No of data sets used in the model : 7
c.Independant variables used in the model : 4

Variables used in the model are ......

variable 1 is fuel t/h
variable 2 is %a
variable 3 is %b
variable 4 is %c
variable 5 is SPM kg/h

Fuel Mix effect on emission of SPM

solution is ....

1 coefficient: 8.09593
2 coefficient: 1.96965
3 coefficient: 2.20512
4 coefficient: 1.61256
5 coefficient: -200.31056

Last coefficient in the row
is a constant

observed spm	simulated spm	error term
36.56941	36.60645	-0.03704
33.58327	33.95967	-0.37640
31.43477	30.98120	0.45357
36.68230	36.55026	0.13204
32.21629	31.98787	0.22842
24.82698	25.36722	-0.54024
11.94684	11.80725	0.13959

Standard Error of the estimate = 0.34874

SCIENTIFIC MODEL OUTPUT

solution for the model ....

1 coefficient: 0.97948
2 coefficient: 0.31165
3 coefficient: 0.68219
4 coefficient: 0.00082
5 coefficient: -1.56356

MUTIPLIER (last value) IS .2093887

Table 10.02 Fuel mix effect on SPM emission

observed spm level	simulated by Sci.Model	error term
36.56941	36.86742	-0.29801
33.58327	33.29480	0.28847
31.43477	31.49496	-0.06019
36.68230	36.88757	-0.20527
32.21629	32.02048	0.19581
24.82698	24.74397	0.08301
11.94684	11.97630	-0.02946

Standard Error of the estimate = 0.20971

Table 10.03 Fuel mix effect on SO2 emission

No of data sets used in the model : 7
Independant variables used in the model : 4

Variables used in the model are ......

variable 1 is fuel t/h
variable 2 is %a
variable 3 is %b
variable 4 is %c
variable 5 is SO2 kg/h

fuel t/h	%a	%b	%c	SO2 kg/h
4.1286	37.88935	48.44499	13.66564	257.7516
3.9875	49.84576	38.70094	11.45329	260.2780
4.2455	40.33211	35.88269	23.78518	305.2940
5.1163	30.57287	39.26470	30.16242	375.7290
5.0246	22.36197	37.76619	39.87183	393.8250
5.1197	17.12014	28.45283	54.42701	453.4433
4.7981	14.13684	11.76090	74.10224	498.7904

solution is ....

1 coefficient: 67.41148
2 coefficient: 4.04556
3 coefficient: 2.50810
4 coefficient: 6.37297
5 coefficient: -382.68945

Table 10.04 .Fuel mix effect on SO2 emission

observed SO2	Simulated SO2	error term
257.75159	257.50446	0.24713
260.27802	257.82477	2.45325
305.29401	308.25116	-2.95715
375.72900	376.59595	-0.86694
393.82501	395.31598	-1.49097
453.44330	449.92151	3.52179
498.79041	499.69745	-0.90704

Standard Error of the estimate = 2.27393

SCIENTIFIC MODEL OUTPUT

solution for the model ....

1 coefficient: 1.01627
2 coefficient: -0.03196
3 coefficient: -0.16416
4 coefficient: 0.13805
5 coefficient: 4.52295

MUTIPLIER (last value) IS 92.10649

observed SO2	Simulated by Sci.Model	error term
257.7516	262.89670	-5.14511
260.2780	254.71419	5.56385
305.2940	306.10303	-0.80901
375.7291	380.08191	-4.35285
393.8251	394.22226	-0.39719
453.4434	443.16879	10.27457
498.7903	503.59442	-4.80408

Standard Error of the estimate = 5.85711

TABLE 10.01 A.

Emission Data for Environmental Management

DATE	EQPT	CODE	SPM	SO2	RATE_EMI
30-May-95	BLR3	BLR	58.0	285.0	21000
30-Jun-95	BLR3	BLR	100.0	352.0	19500
31-Jul-95	BLR3	BLR	106.0	950.0	19800
30-Sep-95	BLR3	BLR	94.0	990.0	10250
30-May-95	BLR4	BLR	70.0	194.0	46200
30-Jun-95	BLR4	BLR	102.0	375.0	39500
31-Jul-95	BLR4	BLR	62.0	944.0	25000
31-Aug-95	BLR4	BLR	76.0	1015.0	31400
30-Sep-95	BLR4	BLR	89.0	1005.0	25650
30-May-95	BLR6	BLR	104.0	244.0	43250
30-Jun-95	BLR6	BLR	95.0	438.0	44800
31-Jul-95	BLR6	BLR	95.0	812.0	85000
31-Aug-95	BLR6	BLR	184.0	762.0	45300
30-Sep-95	BLR6	BLR	110.0	783.0	51000
31-Jul-95	CRHTR	PRO	80.0	815.0	65050
31-Aug-95	CRHTR	PRO	80.0	1117.0	52500
30-Sep-95	CRHTR	PRO	64.0	980.0	63200
30-May-95	EHTR	PRO	74.0	387.0	48500
30-Jun-95	EHTR	PRO	88.0	428.0	49250
31-Jul-95	EHTR	PRO	92.0	1015.0	41200
31-Aug-95	EHTR	PRO	125.0	704.0	45000
30-Sep-95	EHTR	PRO	62.0	695.0	44450
30-May-95	FHTR1	PRO	91.0	458.0	17100
30-Jun-95	FHTR1	PRO	74.0	368.0	17500
31-Jul-95	FHTR1	PRO	86.0	731.0	21450
31-Aug-95	FHTR1	PRO	14.0	200.0	23350
30-Sep-95	FHTR1	PRO	70.0	983.0	17500
30-May-95	FHTR2	PRO	46.0	841.0	116600
30-Jun-95	FHTR2	PRO	44.0	480.0	118000
31-Jul-95	FHTR2	PRO	46.0	893.0	108500
31-Aug-95	FHTR2	PRO	43.0	965.0	198000
30-Sep-95	FHTR2	PRO	45.0	895.0	107200
30-May-95	VBHTR	PRO	101.0	428.0	18700
30-Jun-95	VBHTR	PRO	98.0	660.0	18750
31-Jul-95	VBHTR	PRO	91.0	968.0	18700
31-Aug-95	VBHTR	PRO	35.0	1164.0	20750
30-Sep-95	VBHTR	PRO	87.0	650.0	19000

PRO *Process heater*
BLR *Boiler*
Rate_EMI *flue gas rate in nm3/hr.*
SPM,SO2 *ppm*

Table 10.05 . Fuel mix effect on atmospheric pollution

a.Ultimate Analysis Data

weight % dry basis	*a fuel oil1*	*b fuel oil2*	*c fuel gas1*
carbon	85.6571	86.7564	80.0005
hydrogen	11.1098	10.0001	15.9876
oxygen	0.0000	0.0021	0.0000
sulfur	2.5123	1.2006	4.0064
nitrogen	0.0332	0.7502	0.0055
ash	0.6876	1.2906	0.0000

b.Flow Rates t/hr

Run No	*a*	*b*	*c*	*total*	*%a*	*%b*	*%c*
1	1.5643	2.0001	0.5642	4.1286	37.88936	48.44499	13.66565
2	1.9876	1.5432	0.4567	3.9875	49.84577	38.70094	11.45329
3	1.7123	1.5234	1.0098	4.2455	40.33212	35.88270	23.78518
4	1.5642	2.0089	1.5432	5.1163	30.57287	39.26470	30.16242
5	1.1236	1.8976	2.0034	5.0246	22.36198	37.76619	39.87183
6	0.8765	1.4567	2.7865	5.1197	17.12014	28.45284	54.42702
7	0.6783	0.5643	3.5555	4.7981	14.13685	11.76091	74.10225

c.Ultimate Analysis of Fuel Mix (from above data)

Run No	*carbon*	*hydrogen*	*oxygen*	*sulfur*	*nitrogen*	*ash*
1	85.41664	11.23879	0.001017	2.081025	0.376765	0.885758
2	85.43467	11.23900	0.000813	2.175783	0.307513	0.842214
3	84.70613	11.87180	0.000754	2.397001	0.283890	0.740426
4	84.38257	12.14534	0.000825	2.447922	0.306373	0.716969
5	83.81687	12.63558	0.000793	2.612646	0.292939	0.641171
6	82.89116	13.44890	0.000598	2.952278	0.222131	0.484930
7	81.59472	14.59385	0.000247	3.465194	0.096999	0.248991

d.Emission Levels of Pollutants (Theoritical)

Run No	*fuel kg/h*	*weight %a*	*weight %b*	*weight %c*	*so2 kg/h*	*ash kg/h*
1	4.1286	37.88936	48.44499	13.66565	257.7517	36.56942
2	3.9875	49.84577	38.70094	11.45329	260.2781	33.58328
3	4.2455	40.33212	35.88270	23.78518	305.2940	31.43478
4	5.1163	30.57287	39.26470	30.16242	375.7290	36.68230
5	5.0246	22.36198	37.76619	39.87183	393.8250	32.21630
6	5.1197	17.12014	28.45284	54.42702	453.4434	24.82698
7	4.7981	14.13685	11.76091	74.10225	498.7904	11.94685

fig 10.02

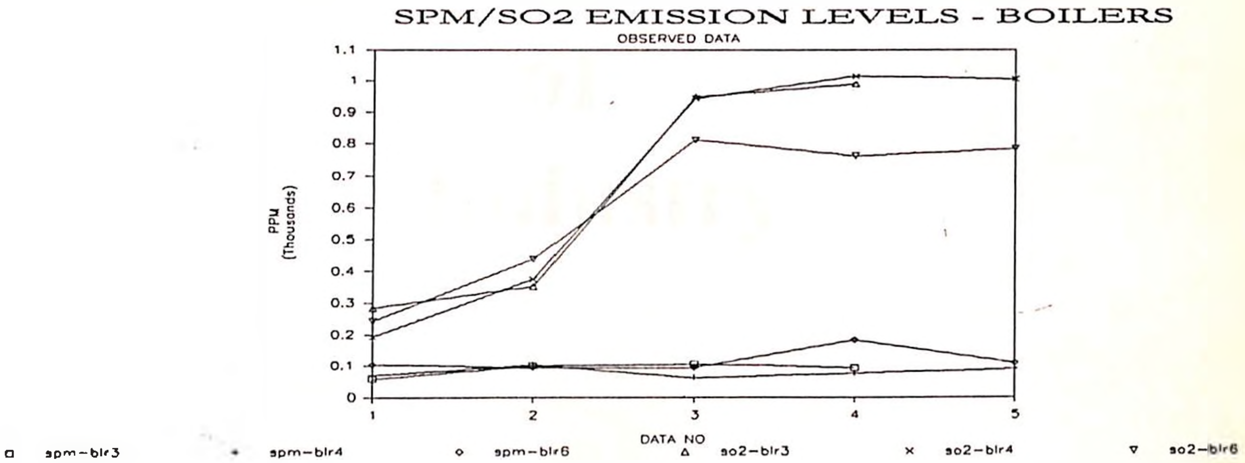
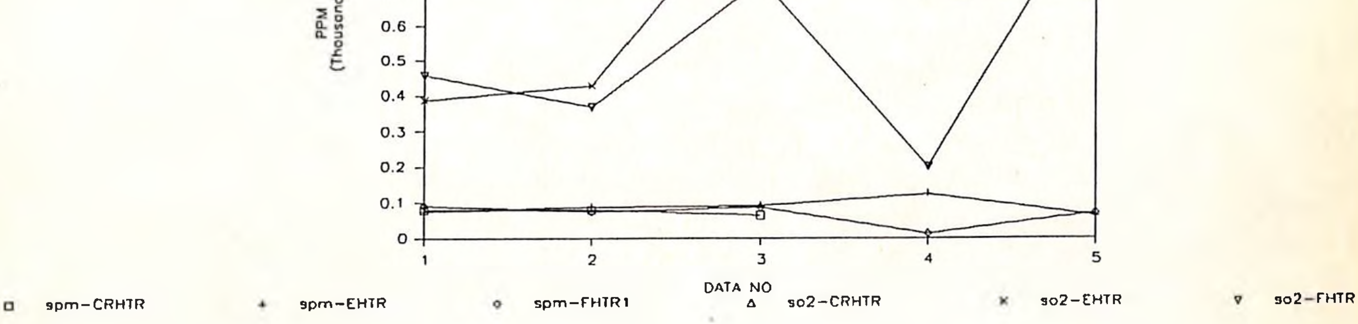


fig 10.03



Monitoring Performance of Industry

The ultimate objective of the organisation is creation of wealth by fair means and reasonable profits. In competitive scenario, there is a pressure to maintain high productivity of the enterprise at all levels. For achieving this, a lot of decisions are to be taken at all levels for which a number of Decision Models were presented in the earlier chapters. A number of conflicting situations may be encountered in real life processes . An integrated information system accessible by all the concerned, may help to optimise the resources so that overall performance is improved .

An integrated information system is very useful to avoid

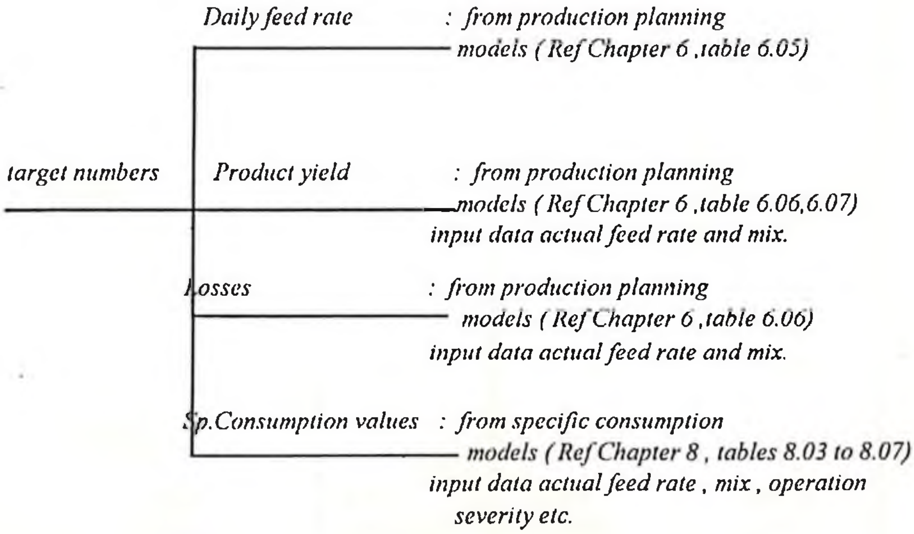
* conflicting decisions at different levels
* non-conformance to internal targets of departments
* disproportionate utilisation of resources at all levels etc.

To overcome problems of communication , the information system should be integrated and made available to all the decision makers . From the decision rules, accepted by all the departmental heads and the chief executive of the organisation , it is possible to avert any misunderstanding . This approach is called *management by objectives,* where the managers concerned are responsible for the results . These results are quantified in terms of 'targets' and will be monitored on a day-to-day basis. Models in turn are used to set the targets .

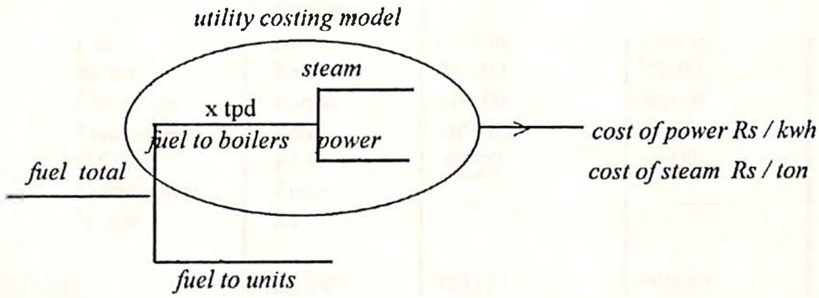
Hence, there is a dire need to develop an integrated information system , capable of highlighting the day to day performance indicators . This is done by integrating the output of required models with actual observations and developing a consolidated output as shown in *format 11.01 which is a replica of format 2.01.*

For effective management of resources , the executive needs more information than what others require .He must be capable of evaluating the cause and effect of alterations in resources mix so that the ultimate action will be profitable to the industry.This step is very imperative as inter departmental decisions could be changed in tune with other parameters so that unity of direction could be achieved .Pre-requisite for such an approach is the understanding of the key parameters , their inter-relation ships and their impact on overall performance.

Format 11.01 draws information from various sources as shown below. Only actual operation information are entered into the format by the user. The format is essentially a template . The template is so designed that once the relevant information are entered , it automatically calculates the rest of the values.



Cost figures for the utilities and chemicals are pre-fixed based on the annual costing figures and are in-built in the template. Whenever the prices are revised , these values will be changed by the user. The program evaluates the variable costs using the cost and consumption rate data of each item on an hourly basis. This is given as *item 6*. Appropriate adjustments are made for internal fuel generation and consumption as shown below.



Operating cost (variable) = *imp power * cost 1 + fuel * cost 2 + chemical * cost 3+ man_power * cost 4*

Since steam and internal power are considered in the fuel cos t, this is not considered for overall costing purpose . However for individual unit performance model , these values will be used.

Format 11.01

Name of Unit: ABC Petroleum Corporation Ltd. **Month/Week/Day:** Daily MIS report

No	Item	unit	target	actual	Variance
1.	*Input:*				
	Feed A	tons	12000	11400	600
	Feed B	tons	10000	9500	500
	Feed C	tons			
2.	*Output:*				
	Product 1	tons	5495	3900	192
	Product 2	tons	12505	12350	871
	Product 3	tons	2880	2200	-164
3.	*Losses:*	tons	143	229	20
4.	*Consumption:*				
	Power	kwh	360000	357000	
	Fuel	tons	1007	1010	
	Steam	tons	4080	4317	
	Chemicals	tons	0.21	0.225	
	Man_power	hrs	720	600	
	OT_Hrs	hrs		240	
	Maintenance	hrs	—	—	
	Spares	Rs	—	—	
5.	*Costs:*				
	Power	Rs/kwh	1.25	1.25	
	Fuel	Rs/ton	1800.00	1800.00	
	Steam	Rs/ton	220.00	220.00	
	Chemicals	Rs/ton	5000.00	5000.00	
	Man_power	Rs/hr	30.00	30.00	
	OT_hrs	Rs/hr	60.00	60.00	
	Maintenance	Rs/hr	—	—	
	Spares	Rs	—	—	
6.	*Total Cost:*	Rs '000	2060.25	2074.65	
7.	*Production Cost / unit*	Rs	93.65	99.26	

*** variance in the case of products is calculated by targeted production for the actual mix minus the actual production.**

**** 50 % of total power is imported . balance internal generation.**

Name of Unit: Month/Week/Day: Daily MIS.

No	Item	unit	target	actual	Variance
8	*Sales:*				
	Product 1	tons	4200	4700	-500
	Product 2	tons	13200	14500	-1300
	Product 3	tons	2100	2000	100
9.	*Inventory:*				
	Product 1	tons	47500	45000	2500
	Product 2	tons	149000	137000	12000
	Product 3	tons	27000	35000	-8000
10.	*Costs:*				
	Feed A	Rs/t	3000		
	Feed B	Rs/t	2800		
	Feed C	Rs/t	2750		
	Product 1	Rs/t	5000		
	Product 2	Rs/t	4500		
	Product 3	Rs/t	2600		
11.	*Running Hrs Data*				
	On stream Hrs	Hrs	24	24	
	Break Down	Hrs	0	0	
	M/E/I/M	Hrs	0	0	
	Prodn Loss	tons	0	0	

Target consumption figures *(item 4)* for power , fuel , steam and chemicals are evaluated by the models as given in chapter 8 (*tables 8.03,8.04,8.05,8.05).*

A Decision flow diagram to evaluate this flexi target is given in fig 11.02

Format 11.01 shown above is a typical display screen using the actual plant information. User enters the minimum information in the data base. The program automatically calculates the target for the actual feed mix from the target values on a pro-rated basis. It is possible to know the actual performance of the unit at any point of time from these data. It is also possible to automate the data entry by Distributed- Digital Control System and is practiced in modern process industries .

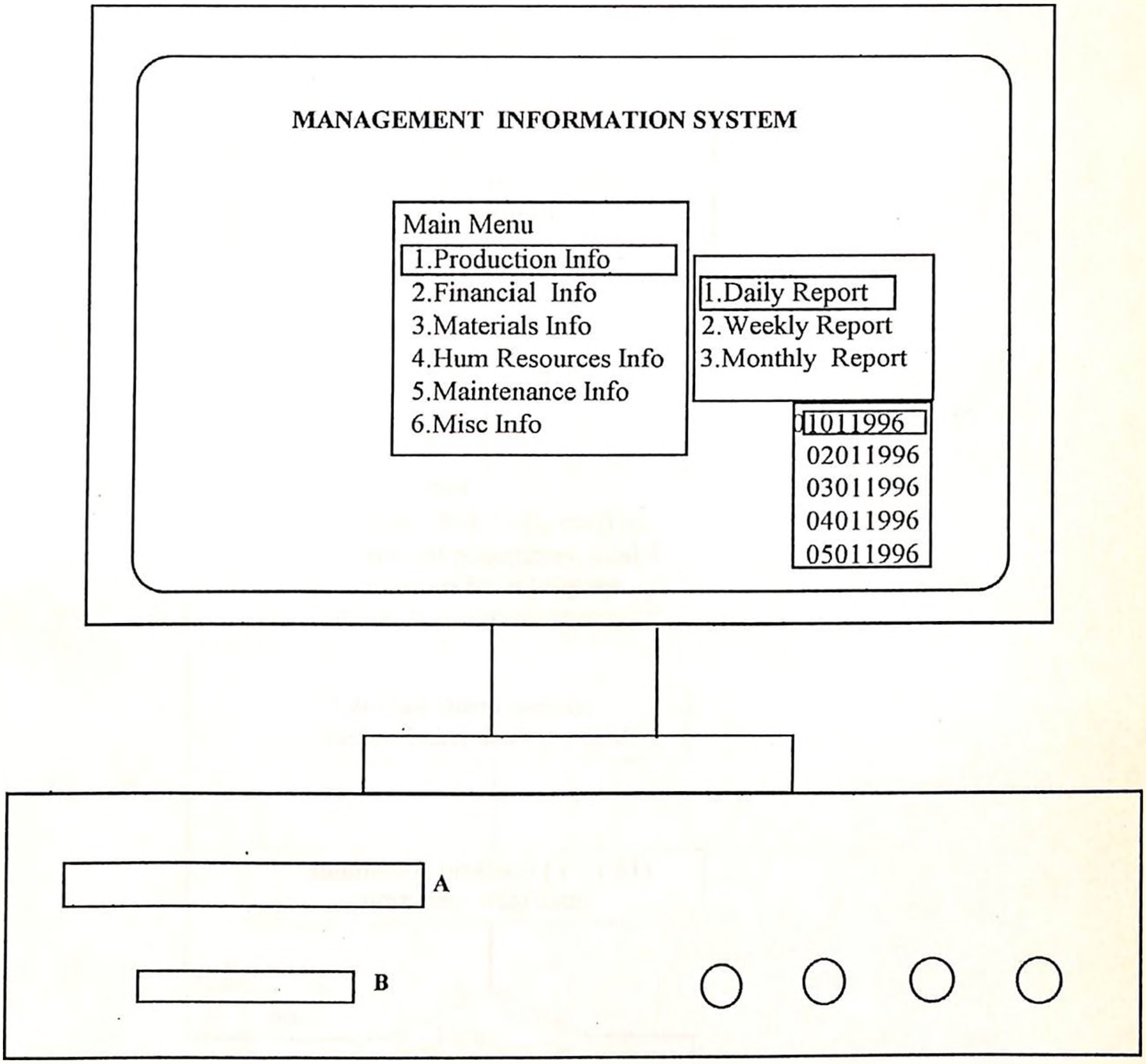
All the consolidated information could be made available on a day-to-day basis by an appropriate design. Day to day operating costs are also evaluated by the costing program and gives an idea to the executive, *what is the current day's operation, what is the operating cost and what is the profit. Finance and materials managers may get the information on inventory levels and sales levels from the above data.*

Above information may be converted into weekly or monthly reports based on the requirement of the users by an auto summation program . For designing the program , certain vital information such as the feed quality, conversion levels at each unit, utility demand etc will be considered. This approach offers variable targets for each type of feed mix. When the feed mix varies, the target product pattern will also vary . Other factors that affect the product pattern are down stream unit feed rates, operating severity, catalyst type, catalyst aging factor etc . Impact of these technical parameters on yield pattern could be identified only with the help of models. This concept of 'flexi targetting ' along with LP model could be effectively used in target setting and monitoring .

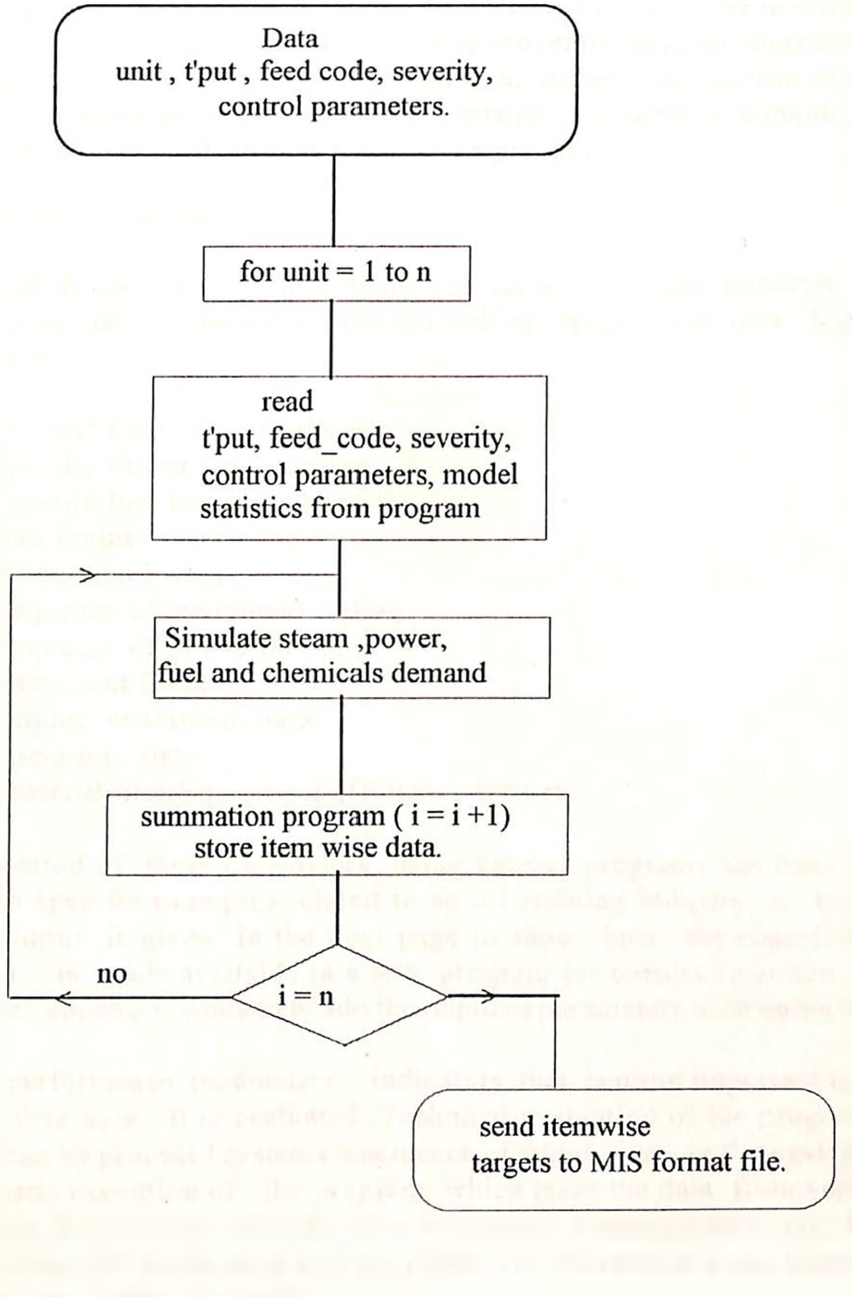
When Lotus 123 is used for setting the flexi targets, **Data Matrix** command may be used to identify the targets for each product for the planned feed mix and rate. Similarly, the targeted product rates may be estimated by actual feed mix and rate using the same command. Impact of utilities , man-power , break-down , maintenace etc are considered in the costing . Since, for the generation of power, internal fuel is used, only the import power cost is considered in the model. Cost of steam , power, fuel etc will be utilised for individual unit costing. The greatest advantage of computerised information system is the computing power of the system and generation of end results which is extremely tedious to achieve by conventional methods.

A typical display screen capable of offering the consolidated information is shown in fig **11.01** with menu arrangements.

fig 11.01 . A typical Display Screen for MIS



Data for the program, could be physically entered in the individual section, which will be accessed by the MIS program , evaluate the parameters and store them in various output files. When once the MIS program is invoked, a menu screen shown above will appear and invoking any program by pressing the return key will show another pull down menu . This will give further options *fig 11.02 . Decision flow diagram for flexi-target setting*



for viewing the daily, weekly or monthly reports.Selection of any item will produce another menu where the choice for day ,week or month will be high lighted. When once an option is chosen and enter key pressed , the program will display the daily , weekly or monthly data respectively.

Case Study: This refers to the example of ABC Petroleum Corporation Ltd which has been high lighted in the earlier chapters. All the output of the monitoring parameters refer to the specific industry.While conventional parameters such as capacity utilisation, run_hrs, fuel consumption, steam consumption etc are useful for monitoring purpose, certain performance parameters are required to be monitored to control the thrust areas of the process.

Role of performance indicators :

For most of the executives, performance indicators are more important as they give pin-pointed information for controlling various activities. Typical indicators are

* Specific Energy consumption.
* Specific Power consumption
* Specific fuel Consumption
* Unit losses
* Production losses
* frequency of equipment failure
* frequency of power failure
* instrument failure
* Employees turn out data
* Operating costs
* Heater/Boiler/Equipment efficiency info etc.

Determination of these parameters using various programs has been high lighted with specific examples related to an oil refining industry. A typical program output is given in the next page to show how the consolidated information is made available in a MIS program for corrective action. The program uses 'append' command to add the required parameters in an output file.

It is the performance parameters / indicators that is more important to the managers , than how it is evaluated .Technical evaluation of the program is normally done by process / systems engineers . Output given in the next page is an automatic execution of the program which takes the data from various input sources. It is obvious from the data that energy consumption is very high for the process and break-up is also available. **This information is very important for analysing the problem in totality.**

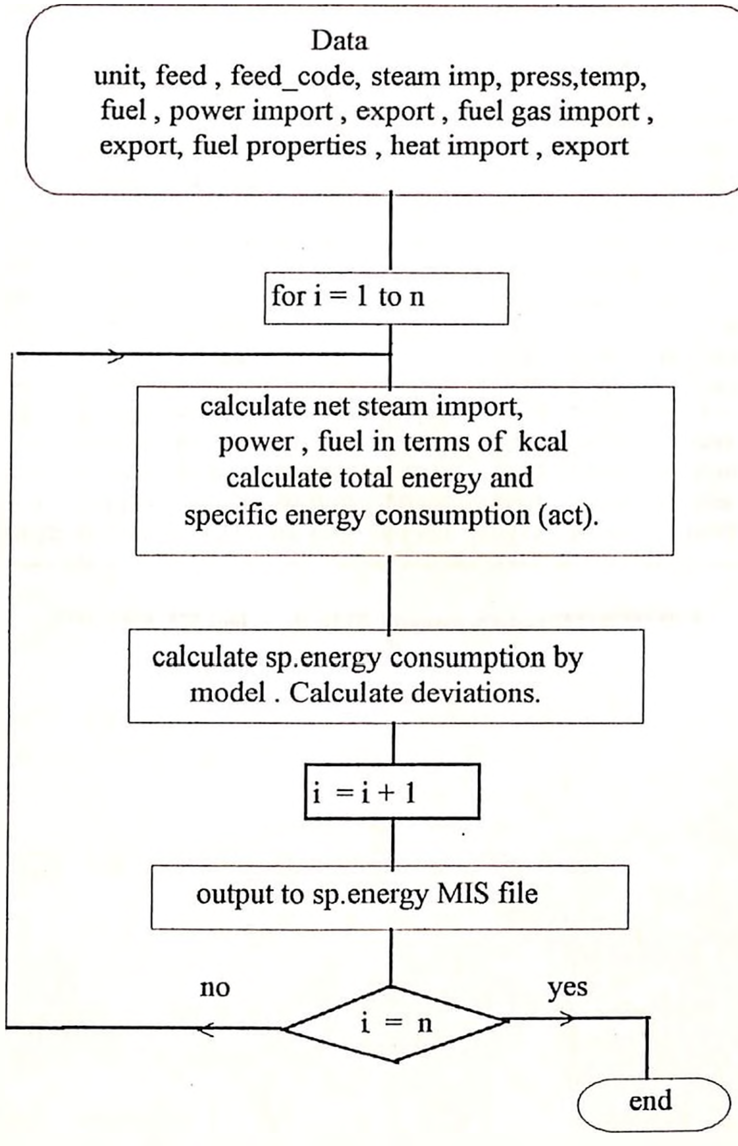
While *format 11.01* gives an overall view of the operation on a daily, weekly or monthly basis, *formats 11.02 and 11.03* give information pertaining to the total heater efficiency and sp.energy consumption of the total system. Invoking loss analysis program will give the various sources of losses as given in *table 9.03, 9.04 and 9.06 in chapter 9*. Following information are available to the manager from *format 11.02.*

* Which heater / boiler is operating under lower efficiency ?
* What is the reason for the loss of efficiency (excess air , leaks , Radiation Convection losses ? etc)

From the *format 11.02.* the performance of overall system is found to be good. However, the efficiency could be improved further as shown in *format 11.02a* . It may be noted that excess of energy loss equivalent of Rs is around 0.9446 Crores per year and from heat loss point of view priority must be accorded to heaters COBX ,UBX7 and CHXB without delay as they constitute about 60% of total losses. If prompt action is taken by the managers , it is possible to reduce the operating costs and increase profits proportionately.

Format 11.03 is the specific energy consumption program output that is displayed in the MIS program. This displays information such as the specific energy consumption , target value and deviation from target value in terms of kcal/hr. A decision flow diagram to evaluate the specific consumption of energy of each unit is given in *fig 11.03.*

fig 11.03. Decision flow diagram for determining unitwise target for specific energy consumption.



typical output

Format 11.02. *MIS DATA FOR HEATERS AND BOILERS FOR JAN 96*

heater name	*% excess air*	*efficiency % HHV*	*LHV*	*FG loss wt%*	*Wet loss wt%*	*con+rad wt%*	*total wt%*
CHXA	12.5489	84.4549	90.5859	6.4974	7.7977	1.2500	15.5451
CHXB	14.2865	84.2648	90.3820	6.5975	7.7977	1.3400	15.7352
DHX	18.5295	83.2104	88.9344	7.0515	7.4180	2.3200	16.7895
RHX	21.6972	82.9410	89.4180	6.7175	8.3415	2.0000	17.0590
HHX	15.4591	84.3447	90.5463	6.6149	7.8905	1.1500	15.6553
NHX	18.5337	82.9957	89.1598	6.7503	7.9640	2.2900	17.0043
NHX2	18.5724	83.2379	89.2805	6.8443	7.7977	2.1200	16.7621
VHX	15.4622	84.7213	90.3843	6.9759	7.2227	1.0800	15.2787
FHX	12.8641	83.6750	89.5914	6.6153	7.6097	2.1000	16.3250
CH2X	15.4770	84.3862	90.5122	6.6660	7.7977	1.1500	15.6138
CH3X	15.4591	84.5447	90.7610	6.6149	7.8905	0.9500	15.4553
COBX	24.9888	81.6617	88.3272	6.7004	8.6878	2.9500	18.3383
UBX4	12.6635	84.7423	90.2391	6.9140	7.0237	1.3200	15.2577
UBX5	9.8642	84.2319	89.6956	6.7445	7.0237	2.0000	15.7681
UBX6	12.0916	84.5070	89.9885	6.8794	7.0237	1.5900	15.4930
UBX7	15.0143	84.0500	89.5018	7.0564	7.0237	1.8700	15.9500
HRSGX	33.1346	82.9325	88.3119	8.1538	7.0237	1.8900	17.0675

************* End of MISHTR Program reached *************

Format 11.02A. Convection and Radiation Loss Data

heater name	*% excess air*	*con+rad wt%*	*total wt%*	*Norm con+Rad%*	*saving potentl%*	*mmkcal /hr.*
CHXA	12.5489	1.2500	15.5451	1.25	----	
CHXB	14.2865	1.3400	15.7352	1.25	0.09	0.0180
DHX	18.5295	2.3200	16.7895	1.25	1.07	0.4280
RHX	21.6972	2.0000	17.0590	1.25	0.75	0.1500
HHX	15.4591	1.1500	15.6553	1.25	-----	
NHX	18.5337	2.2900	17.0043	1.25	1.04	0.1560
NHX2	18.5724	2.1200	16.7621	1.25	0.87	0.0870
VHX	15.4622	1.0800	15.2787	1.25	-----	
FHX	12.8641	2.1000	16.3250	1.25	0.85	0.1700
CH2X	15.4770	1.1500	15.6138	1.25	-----	
CH3X	15.4591	0.9500	15.4553	1.25	-----	
COBX	24.9888	2.9500	18.3383	1.25	1.70	0.6800
UBX4	12.6635	1.3200	15.2577	1.25	0.07	0.0056
UBX5	9.8642	2.0000	15.7681	1.25	0.75	0.1200
UBX6	12.0916	1.5900	15.4930	1.25	0.34	0.0675
UBX7	15.0143	1.8700	15.9500	1.25	0.62	0.4568
HRSGX	33.1346	1.8900	17.0675	1.25	0.64	0.1250
Total						2.4639

Equivalent fuel loss/day	5.91336
Cost eqvt in Rs/d	26610
Excess energy loss eqvt in Rs Crore/yr	0.9446

Format 11.03. S P E C I F I C E N E R G Y A N A L Y S I S.
(PROCESS UNITS)

UNIT Name	T'PUT t/hr	SP-NRG actual '000 kcal/t	NORM '000 kcal/t	EXCESS CONSUMPN
crude	500	235.773	195	20386.500
vb	100	669.531	580	8953.101
cru	60	633.200	550	4992.001
hds1	100	381.811	285	9681.101
hds2	120	359.054	285	8886.500
hds3	100	409.871	285	12487.100
crude b	400	250.989	185	26395.700
vac1	100	676.971	500	17697.100
vac2	500	686.076	500	93037.990
bitum	100	676.971	320	35697.100
treatr1	50	450.290	320	6514.500
treatr2	75	338.201	320	1365.099
lpg	35	684.586	590	3310.499
blr1	100	220.971	150	7097.101
blr2	100	165.065	135	3006.500

Total Energy Consumed kcal/h : 1.034358E+09
Excess Energy consumed in kcal/h 2.595079E+08
Equivalent Fuel in kg/h : 25441.95
Fuel Calorific Value in kcal/kg 10200
Steam Enthalpy for consumption 680
Steam Enthalpy for generation 620
Specific Energy is given as : '000 kcal/ton

Tables 11.01 and 11.02 given above refers to heater efficiency, energy loss break-up, and specific energy consumption of the total system that may be used to monitor the performance of energy consumption centres . From this information, decision makers at appropriate level will be able to identify the high energy consuming centres for necessary action. Other monitoring parameters are also automatically calculated by the program and displayed in appropriate files.

In a similar way financial performance of the unit is also displayed on a daily , weekly , monthly basis on invoking the financial info menu. Information available in this menu are

1.daily sales
2.cash expenses - with cost centre wise break-up.
3.total cash-inflow
4.cash-out flow
5.work in process
6.losses etc.

This information is very critical to the financial executive to evaluate the financial performance of the enterprise and identify major cost centres, profit centres etc for taking appropriate steps such as budgeting , fund mobilisation, investment decisions etc. From day-to-day performance point of view, *items 7 thro' 9 given in format 11.01* is of great significance as they offer cash_inflow , price variance and inventory details.

Materials information will be available from the MIS system on *invoking item no 3 (Materials info command)* of the main menu.The information of great importance for materials section include

1.Specific Consumption of feed stock
2.Inventory level of feed stock
3.Inventory level of consummables.
4.availability of class A,B and C items for the total operation and maintenance.
5.Feed quality etc.

These information are also available in the *format 11.01* on a day-to-day basis which could be used for *MRP decisions. (Materials Requirement Planning).* From cost control point of view, this information is very important as *dynamic optimisation* has to be carried out between conflicting variables such as feed quality, cost and yield pattern on one hand and the cost of losses , operation and maintenance on the other .

Invoking ***Human Resources Info*** from the MIS program *(item no 4)* gives information such as employee working hours unit - wise, section - wise, department - wise etc. This also offers information such as over-time hours , normal working hours etc of each section. This could be used to determine

1.Labour productivity of the section.
2.Employee Turn-over details.
3.Absenteism (section wise)
4.Motivation level of employees etc.

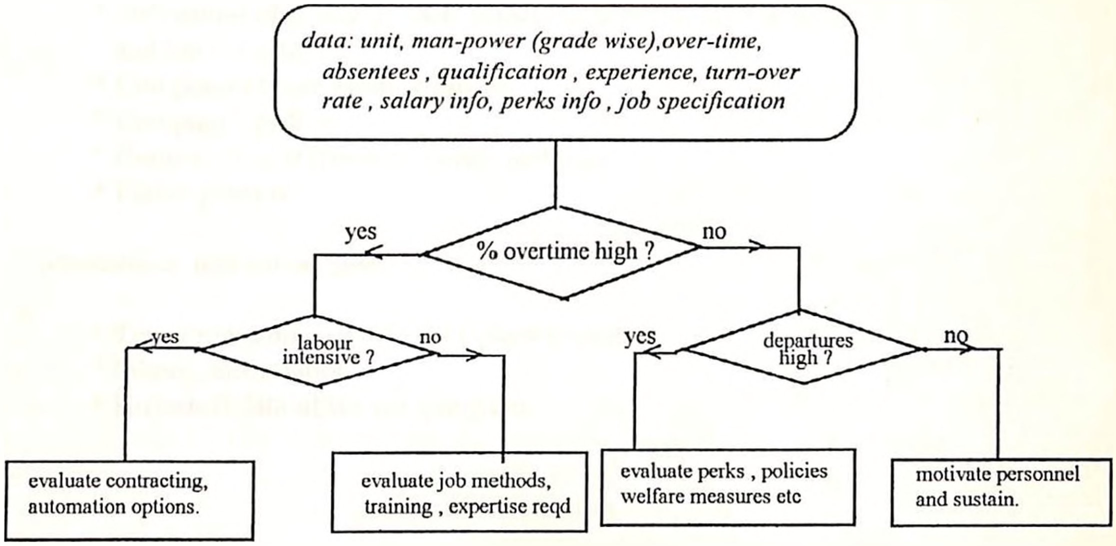
This could be used for man-power planning , training needs , additional - recruitment, man-power cost control , job-rotation etc. Since trained human-resource is an asset to the organisation, there is a need to monitor the section as intensively as others. In fact human resource is one of the factors that is considered critical in *SWOT* analysis, when new projects are launched or diversification decisions are taken. Continuous high over-time expenses could indicate inadequacy of the man-power , inefficiency of the personnel and/or untrained man-power in the section . This information is also available from *format 11.01 item no 4 and 5* and daily attendance information / time sheet . An innovarive HRM manager could use this information for taking many decisions pertaining to Human Resources Management of the organisation. In sections, where toxic chemicals are handled and where more manual jobs are involved, the organisation has to plan for adequate replacement / transfer etc to keep the job going.Decisions related to abandoning of certain operations, contracting , Automation etc are based on the Human Resources Info. *Fig 11.04 is a decision flow diagram* related to Human Resources Managment for taking various decisions which control the cost of operation of the enterprise.

Maintenance Management information module will be invoked when *item no 5* is selected from the *main menu.* This section gives information such as

1.Running Hours of the Individual Unit.
2.Equipment Break-down information.
3.Type of failure (electrical/mechanical/instrument/misc etc)
4.Down-time hours and production loss .
4.Component / Section failed.
5.Maintenance cost incurred etc.

Item 11 of format 11.01 covers this aspect .From the frequency of failure and break-down analysis , equipment replacement and/or maintenance decisions may be taken .Decision flow diagrams for identification of the impact of machines on productivity and replacement decision is given in *figs 2.01 and 2.04 in chapter 2.*

Fig 11.04 . Decision flow Diagram for Human Resources Management.



Invoking Miscellaneous Info option *(item no 6)* , gives information not covered in the other sections.They include technical , non-technical, and Administrative Information as given below.

Technical Data (design) :

* Unit flow diagrams
* Material Balance
* Utility / Specific Energy consumption data.
* Loss data

Above data will be in condensed form and gives an overview of the total process covering only important technical details.

Non Technical Information :

This is subdivided into Administrative Info, Secretarial Info and Miscellaneous Info. Administrative Information covers information

* Unit-wise man-power (actual)
* Age profile of employees.
* Organogram
* Job description
* Responsibilities and duties of each cadre of employees.

Secretarial Information covers

* Delegation of power of each departmental head, section head and top executives.
* Companies Share holding profile.
* Company's policy
* Company's performance current and past
* Future plans etc.

Miscellaneous Information covers

* Tour Programme of officers (place / venue)
* Library information.
* Historical data of the company etc.

Integrated Information

Since this *integrated information* is available to all the decision-makers in one place and the data-base is common, every executive is aware of the problem area more precisely and clearly so that remedial actions can be initiated without delay. This type of systematic approach improves the overall productivity of the enterprise multifolds as timely action reduces production loss and enhances resources utilisation efficiency.

Ultimately *productivity of the enterprise* could be maintained high only when all the resources such as men , machine, materials , money and above all time is optimised to meet the end results. For this purpose, *right information must be available at the right time* for effective control and performance monitoring. All the programs, highlighted above aim at unifying the information from various sections into performance parameters .

The ultimate success of information technology is dependent on

* how well the parameters are defined?
* what relation exists between parameters ?
* which are controllable and indogeneous ?
* whether the current performance is in line with flexi targets ?
* how can this be improved

and so on. Absence of information classification and processing , results in mere raw data of infinite size having ' zero value '. Hence appropriate information design and processing is imperative for the success of computer-based decision support system and this is highly system specific.

Conclusion:

This thesis has drawn a lot of information from the papers published and / or presented by the author(s) in various forums, magazines and technical journals. Most of the papers are related to productivity analysis or improvement using various models and performance monitoring approaches . *MIS technical information* section of the menu gives information pertaining to product quality , safety management etc using the actual performance data . *(20 ,65)* .Using these data, decision makers shall be able to identify the safety performance, accident rate, product quality give away etc to take appropriate actions. Since the data are made available in ASCI format, all modelling programs may access the data in file mode to develop performance parameters as given in the earlier chapters. Information Technology approach covered in this thesis has been found to be very effective in improving the productivity of the complex industry as this covers all resources i.e. men ,machine , materials and money . This is a very effective tool for corporate planning to take *diversification decisions .Even this could be automated by net cash-inflow , demand analysis and sales performance models.*

In the absence of computer-aids, these decisions could have been either delayed or impossible in many cases. In the globalisation scenario, this is the most effective route for *productivity management.*

Chapter 12. Conclusion

This thesis highlights design and practice of various techniques for efficient management of industries using the information base in compter-application programs and developing an effective Decision Support System for taking appropriate decisions.

Decision making is the prelude to action. Industry consumes resources like *men, machine, materials and money and the objective of the industry is to make reasonable profits and increase the return on investment*.In competitive market scenario, all the resources are to be optimised at each level. This warrants effective decision-making at each level .

Each decision is based on the information which could be a technical information, non-technical information , administrative information , managerial information etc. In many cases, technical and managerial decisions are inter linked. In earlier days, all decisions were based on the individual experience and expertise level of the individuals. Ultimate performance of the industry rested on the quality of decisions of the top executive. In competitive scenario, this approach is not feasible. The actual performance of the industry is now determined by certain performance indicators such as

* specific consumption of raw materials.
* specific consumption of utilities and chemicals.
* specific consumption of energy .
* capital productivity
* labour productivity etc.

In scientific management of industries all these performance indicators are to be evolved by models using the actual data.Methodology of developing various models , using these models to real life situations , developing flexi targets, optimisation of resources, evaluating and developing performance criteria / parameters, monitoring the performance of each section by computer-based information, information design, processing and generation of required reports, developing information network etc were covered in the earlier chapters .

In earlier managerial style (autocratic) ,production chief was the sole decision maker. He will decide

* what to produce
* when to produce
* how to produce etc and all decisions were individualistic . Organisation's performance depended totally on the individual performance. This approach had

been found to be disastrous when the complexity of the industry increased and the enterprise had to face severe competition . Number of sick industries have risen in the past due to improper planning , non-optimal utilisation of resources etc which resulted in *data base management concept* where, the decision-makers paid attention to the numbers such as production rate, cost of production , expenditures , demand analysis etc . While this approach is superior to the *earlier 'add-hoc' management , this suffers from the set-back of handling enarmous data and the success depended totally on conceptualisation and understanding level of the 'decision-maker'.*

This situation resulted in *'modelling concept'* where the operating data could be used to develop performance models using statistical / mathematical simulation techniques. This approach may be applied to all functions, where computer-application could improve the performance and productivity multifolds. Since information is the key to organisational performance, there exists a dire need to check the data at each stage before a final evaluation is made . From the various examples given in this thesis, one could see how 'computer-application' and 'Decision-models ' are useful for taking appropriate decision at the right time.

These application programs are of immense use to identify the problem area accurately and may be used for trouble-shooting process / operational / logistic / maintenance problems etc using the concept of ' expert system' for which the basic models will be the input source. Hence, this methodology helps in institutionalising the the experience of experts for tackling day-to-day problems more easily in their absence. Even non-professionals may be able to tackle the problem with ease. An innovative manager could even use this for training his personnel for improving the value of his human resource which is an asset by itself. (*ref 20, 21 ,33, 34,62,63*)

Typical examples are covered in papers (*ref 60, 61*) with reference to a heater and ammonia plant performance evaluation . Applying the *'flexi-targeting' technique*, it had been identified that the performance of the system is better because of optimum capacity utilisation of the system and not due to any operational excellence , though the first look at the data is deceptive . An enthusiastic manager may claim that he achieved excellence in performance due to efficient operation , whereas even a normal operation could have given the same results. This analytical approach may be applied to any system as this a very *powerful performance evaluation tool* . In competitive industrial scenario, this is imperative not only for the survival of the industry, but also to improve the productivity of all resources. Ways and means of achieving them highlighted in this thesis are mostly real life cases and are successfully practised.

Conclusions:

Effective and efficient management of process industries could be achieved only with the help of real life operating models. This starts right from demand analysis for the product / product(s) being manufactured. A real life model helps in modifying the production targets to a realistic demand scenario and reduces the gap between demand and production and takes care of the dynamic situation .

Models are again useful for

* micro level production planning
* resources optimisation
* flexi-targeting and real performance evaluation
* trouble-shooting etc.

Modelling technique has undergone drastic changes and combining simulation methods it is possible to visualise in advance the industry scenario and the impact on performance. This saves the expenses of experimentation and the associated risks. *Combining process simulation and EORT modelling.* a lot of design improvements could be made to fine-tune the former, which is heavily built-on assumptions. This change has resulted in energy-efficient and cost-effective technologies. The entire work of this thesis has focussed attention on micro level as well as macro level models and covered the entire range of industry. The objective function of each each model had been high lighted in the program outputs.(*Example of ABC Refining Co has been covered elaborately in each section*)

This approach ultimately reasults in

* *high productivity.*
* *high profitability*
* *longer run lengths*
* *longer plant and machinery life*
* *low operation and maintenance costs*
* *optimal operation*
* *high morale*
* *better human resources utilisation etc*

which is the ultimate goal of effective management.

Future work: Productivity has no limit so long as no one cares where the credit goes. Though the thesis covered a number of modelling techniques and operating models, the advancement in computerisation and control calls for more refinements in the design of decision support system. The methodology given in the thesis is a combination of fragments of various models at micro level which were synthesised to offer a macro level decision support system.

In the examples covered in earlier chapters , all relevant data were fed from the console in batch mode or file mode. With the advent of advanced control system and development of micro processors , it is now possible to have precise control of the parameters by automated continuous data transfer.

Advanced control without an optimization software cannot be effective as the set points for the control are to be determined by the output of the program at various stages, which are ever dynamic. Since this is system specific , future research in this area should cover this aspect of dynamic optimization. Future research in this area may cover 'on-line' trouble shooting using real time data and predict the various courses of action . Possibility of establishing the product pattern for the feed mix, adjusting the process parameters automatically in conformance with the demand and unit operating constraints is an area that could be covered in future.

Taking advantage of the 'expert system and artificial intelligence' , various courses of action may be analyzed and suggestions may be presented to the 'decision-maker' at each stage .This is also identified as an area of research for future due to inadequate coverage of this aspect. This approach when synthesized could offer an integrated production planning and control at National Level which will be the optimal solution at macro level. When once this stage is reached, the country's productivity and GNP will go up at a faster rate.There is no substitute for a computer-aided management system , especially in a country like ours, where expertise is dominant at all levels.

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13. Summary

The objective of this thesis is to indicate the methodology of '*Computer Applications and Decision Support Systems for Efficient Management of Process Industries'.* with examples . This has been accomplished in various chapters of the thesis.

Impact of various internal and external factors like customer behavior, competition, product substitutes, market image, product cost, reliability, service to customers , quality, standards, government regulations etc. on industry performance has been discussed in *chapter 1* .Planning mechanism is imperative for foreseeing future scenario to take appropriate decisions. Decision mechanism and classification are also covered in this chapter.

Impact of information flow , concept of productivity analysis and performance parameters for achieving resources optimization using resources mix model and transformation model has been covered in *chapter 2*. This chapter explains how cybernetic control model and plant performance analysis model could be used with the help of information and data processing to arrive at the decisions. Design of information flow system , planning and control mechanism using unitwise information are also covered.

Chapters 3,4 and 5 cover various models and modelling techniques that could be used by process industries for taking decisions. Typical models related to production, maintenance, marketing, materials , financial and human resources management are presented in these chapters.Impact of the combination of variables for achieving optimal solution and usage of models are explained in *chapter 3*. Operation Simulation models help in energy conservation, operating costs, higher throughput etc. They use plant data and are capable of identifying the design discrepancies and deficiencies .Methodology of OSA modelling is covered in *chapter 4 and an* example related to a *naphtha cracker* operating on a different feed stock than what was originally designed is covered in this chapter with program output. *Evolutionary Operations Research Technique models* , their basics and applications are given in *chapter 5* . EORT model application given in this chapter refers to the *shift conversion section a fertilizer industry* . The objective of the model is to determine

* *whether the converter performance is okay ?*
* *what factors cause abnormalities ?*
* *which combination of parameters will increase conversion ?*
* *whether to continue or shut-down etc.*

This gives the output of *a time-dependent model (example 5.01)* , multi variable model *(example 5.02), converter performance model , catalyst aging model etc.* Variables affecting the performance is also high-lighted in the output of each program using 'what-if' analysis..

EORT model applications related to the performance monitoring of *Sour Water Stripper and Energy systems Analysis* are also covered in this chapter. Impact of various parameters on stripping efficiency and energy efficiency are given in both the examples to indicate how *EORT* serves as a modern DSS tool.

Performance of the industry starts from demand analysis whether it is a new unit or an existing unit. *Chapter 6* covers an in-depth application of *Production Planning models for a Refining Industry.* The case study refers to a fuels refinery named *ABC Petroleum Corporation Ltd.* Demand forecast model development method is given in the chapter based on six years of demand data for petroleum products. Four models are developed for the same input data. (*linear, non-linear, exponential and polynomial*).

Using Lotus 123 Regression Method , demand models for LPG , Light Distillate, Middle Distillate , Heavy distillate and Plant fuel and Losses have been developed and the forecasts given in *table 6.02.* For maximisation of the profits of operation within the imposed constraints, a typical *LP model* is given in *tables 6.03 and 6.04.*This also covers setting up of monthly production targets , and daily/hourly production rates taking into consideration planned shut-down, un-planned shut-down, plant emergencies etc for monitoring purpose.

Problems faced by the operating units are l*ow capacity utilisation , low efficiency, high operating costs, equipment failures , high losses, high energy consumption costs etc.* Each decision-maker has to first identify the true performance of the system from the operating data using *flexi-targeting* methods . Production Analysis using EORT / LP models is given in *table 6.10.* Impact of capacity utilisation on plant fuel and losses , impact of fuel mix on yield pattern and *PFL* are also estimated using these models .To avert linearisation of non-linear variables and evaluating the impact of shut down time on *PFL* , shut-down analysis and Process Loss models have also been incorporated *(fig 6.09) in this chapter* .

Utilities play a dual role in plant operation. Process industries are *utility dependent* and many industries could not achieve the planned capacity utilisation because of non availability of power, cooling water etc. Capacity utilisation of the utility system is related to system efficiency and operation costs . Unless optimal operation of utilities is ensured , *the operating costs will tend to be high. Chapter 7 on 'Computer-aided utility management '* covers this aspect with the help of models related to steam - power consumption , Combined heat-power cycle , boiler efficiency, turbine efficiency, cooling system efficiency , corrosion-scale formation tendency etc. This covers complete optimisation technique of the utility system related to the process industry. *(case: ABC petroleum Corpn Ltd)*

Process Engineering is the real brain behind the productivity of process industries.Many decisions are interlinked to process decisions. *Chapter 8* refers to modelling applications related to corporate planning , diversification , performance monitoring of liquid-liquid extraction unit , energy-consumption etc. Example on corporate planning takes the case of a petro chemicals refinery (*ABC Petro Chemicals Corporation Ltd*) which produces value-added aromatics.Impact of feed mix on aromatics production, profitability and strategies are simulated using **EORT** models . *Second case study* is a micro-level application for prediction of *extraction efficiency* of a liquid-liquid extraction system. Examples of **EORT** model applications to predict the *specific consumption of energy , steam , power and fuel of the individual unit* is also shown in this chapter.

Energy consumption of process industries constitute 60 to 70 % of operating costs. Reduction of specific energy consumption reduces operating costs and increases operating profits of the industry. This is an area , where utmost attention must be focussed by the managers . While the performance of energy intensive equipment like heaters , boilers, turbines, compressors, pumps , heat-transfer equipment etc are evaluated by energy balance , *ABC analysis* may be applied to the total system for effective energy management . This is covered in *chapter 9 on 'EnergyManagement Applications'. The case study refers to 'ABC Petroleum Corporation Ltd '. ABC analysis* program is used to identify **class A sub-systems and equipment for performance monitoring.** Efficiency of heaters and boilers using energy input-output data is given in *tables 9.07 and 9.08.* Identification of energy losses from convection and radiation section of heaters / boilers due to poor insulation efficiency is covered in this chapter. **EORT** models are used to monitor the performance of turbines ,compressors, pumps, heat transfer equipment etc. Impact of operating variables on efficiency and energy economics is also covered in this chapter.

With the advent of industrialisation and energy consumption industries tend to pollute our environment. Mandatory environmental regulations such as **EPA ,CAA , CWA** are to be complied with by all the process industries. Information pertaining to emission rate, pollutant levels, effluent quality and discharge rate are also required for controlling the operation.These aspects of environmental management are covered in *chapter 10.*

Chapter 11 covers the *design of information system menu , development of performance indices and segregation of information function-wise for taking control decisions.* This is the most important part of **MIS**, as information provided in this section is synthesised from the various model output given in earlier chapters. *Format 11.01 is a typical MIS* information which covers *operation , maintenance , finance ,materials , maintenance and human resources information in terms of the required performance parameters.*Complete details of information available from this section and a number of decision flow diagrams are also presented in *chapter 11.*

Chapter 12 is the concluding chapter that explains the information need , decision making , data-base requirement , modeling theory and application, development of performance parameters using models and translating the model output into decisions by sensitivity analysis and prediction of futuristic performance etc. This also covers the future scope of work for further research in the area using **AI** , **Expert System** etc. for institutionalising the valuable experience and expertise gained by the enterprise .

Thus, the thesis has covered the *total resources management* (**men , machine , materials and money**) and optimisation methodology using simple and easy to use models / programs. Since the performance data is accessed by all the concerned decision-makers of the organisation in the required form and style , effective and timely decisions could be taken by all concerned very easily . For improving the performance , *stagewise LP / NLP models* may also be used to fine-tune the operating parameters for achieving higher performance .

This system is found superior to the conventional management system as the decision-makers are aware of the problem areas more precisely for taking timely action in the right direction. This approach offers scope to visualise the *'future scenario' by 'what-if' analysis,* without involving the **costly and time-consuming experimentation .**

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