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MAY, 1971
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INTRODUCTION

This seminar might be regarded as the coming of age of Operations Research in Australia. Not only was it the first National Conference of this type held in Australia in that its success depended on active participation and collaboration of all the various state wide O.R. groups, but also this meeting was the occasion of a unanimous agreement amongst these groups that an attempt be made to form a cohesive National Society. In fact we can now proudly announce that such a society came into existence in January, 1972. It is known as the Australian Society for Operations Research Incorporated, and we are happy to report that the total foundation membership is 784. (Sydney 217, Victoria 151, South Australia 115, Hunter Valley 111, A.C.T. 88, Wollongong 74, Western Australia 28) We are all particularly indebted to Mr. R.W. Rutledge, Chairman of the now defunct Australian Joint Council for Operations Research, and also to Mr. B. Kennedy (C.S.I.R.O. Division of Building Research) and Mr. G. O'Meally (Australian Gas Light Co.) for their leadership, patience, insight and hard work in at long last bringing us all together and hopefully stripping us of our parochialisms.

Another event indirectly associated with this conference was the initiation of the first professional post graduate course specialising in O.R. in Australia, this course leads to the M.Sc.(O.R.) degree and was presented for the first time at Wollongong University College in 1971. The course was designed in consultation with the Systems Engineering Group at Australian Iron and Steel to train specialists in the mathematical and computer techniques of O.R.
The conference consisted of a formal presentation during the day and an evening session and dinner during the evening. We were most fortunate to have as Chairmen:- Mr. W.B. Burgess, General Manager, Australian Iron and Steel Pty. Ltd., Port Kembla. Mr. R.J. Pearson, General Manager, Metal Manufactures Limited, Port Kembla. Mr. S.W.H. Fairbairn, General Manager, John Lysaght (Australia) Ltd., Port Kembla. Consequently we had representation from the big three industrial giants of Wollongong. Over 150 registered for the conference and most of these came from outside the district.

The papers vary a great deal both in areas of application and depth. It must be pointed out that the speakers were asked to avoid an emphasis on mathematical techniques except in one case where it was considered that an elementary introduction to linear programming was appropriate because of the large number of non-technical managers in attendance. The papers also indicate a wide range of attitude towards the computer, some ignoring it completely and others showing that it is a necessary adjunct to the practices of O.R. Most of these papers demonstrated a considerable cost effective benefit in the areas in which they were applied.

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Department of Mathematics.
A BUSINESS MODEL FOR MANAGERS

S. E. Blanch, N. J. Henderson & K. W. Laing

STATE ELECTRICITY COMMISSION OF VICTORIA

MAY, 1971.
A BUSINESS MODEL FOR MANAGERS

Introductory Summary

1. The Business
2. The Selection of a Suitable Model
3. Macrostructure
4. Microstructure
   4.1 Demand
   4.2 Production
   4.3 Storage
   4.4 Distribution
5. The Logistic System
6. Cost/Effectiveness of the Model
   6.1 Tactical Control
   6.2 Strategic Planning
7. Acknowledgements
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Table 2: Fuel Used in the Industrial Market

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This paper describes how a business model is created and used. In particular it focuses attention on a model which has been developed to represent a typical business comprising production, storage, distribution and demand in a competitive environment.

It describes the situation of the briquette industry in Victoria. The paper is presented not only to illustrate one successful and valuable application, but also to indicate the powerful nature of mathematical models and the way in which all businesses can be so represented. The example used in this paper to highlight the various aspects of model building fits into an emerging pattern of quantitative studies which are contributing toward the preparation of investment decisions by the State Electricity Commission of Victoria.

The paper is presented in the following way:

Section 1 describes the dependence of the economic and business activities of the industry upon the physical, technical and social factors.

Section 2 presents a family of models and outlines the reason for selecting a particular form of model to represent the business.

Section 3 summarises the rationale behind the model, then a detailed account of the model itself is given in Section 4.

Section 5 brings together all the components of the model into a coherent whole under the appropriate title of the logistic system.

Section 6 details the major benefits and the effectiveness of the model and discusses its role as a management tool in decision making.
Apart from its primary objective to generate and supply electricity, the State Electricity Commission of Victoria was also legislated to produce, distribute and sell briquettes* to the primary fuel and raw material markets. Whilst initially serving a purpose of decreasing the State's dependence upon the then sporadic availability of fuel imports, the briquette industry today provides an industrial carbon of unique properties, a cheap form of fuel for various markets and contributes to a highly competitive primary energy situation for the State. The fuel used in the Victorian domestic and industrial markets for the period 1963/64 to 1968/69 is listed in Tables 1 and 2 respectively.

The share of the energy market supplied by briquettes gives some indication of its potential to affect relative fuel prices throughout the State.

The price of a particular fuel is an important determinant which governs its market share and revenue from sales. Volume of sales in turn determines the cost of production and thus net earnings. In this situation it is clear that the lowest priced fuel will command what is known as the pure "economic" buyers. The higher priced fuels rely on the more intangible benefits of their product to offset the price differential and so they attract those buyers more predisposed to attributes other than price. The higher the level of relative prices then prima facie the larger the number of pure economic buyers.

In this way briquettes retain some measure of influence on the price levels in the fuel market which is ultimately to the benefit of the consumer body as a whole. However, this influence is entirely dependent upon retaining the position of the lowest priced fuel in the State. Cost escalation tends to erode the earning base, thus placing management under continual pressure to maintain a rate of return on investment in the face of intense competition.

* The Morwell factories produce brown coal briquettes at the rate of over two-and-a-half tons a minute, night and day, seven days a week. On average, production is about two-thirds the industrial type of briquette (I) and about one-third domestic (II).

To maintain this output, the factories process annually more than three million tons of raw brown coal in a continuous flow from moist coal in its crude state to the finished briquettes.

The raw brown coal used for the manufacture of briquettes has approximately a two-thirds moisture content. Untreated, it breaks up easily during handling, weathers quickly, and for effective use requires to be burned in special furnaces.

The purpose of briquetting is to convert low-grade raw brown coal into a high-quality fuel that possesses uniform characteristics and can be economically transported for use elsewhere. The moisture content is reduced to approximately 15 per cent., thus more than trebling the heating value per pound of fuel. At the same time, the coal is converted into hard, durable blocks of compressed fuel that can be easily stored and handled.
### TABLE 1.

**FUEL USED IN THE DOMESTIC MARKET***

<table>
<thead>
<tr>
<th>Year</th>
<th>Briquettes</th>
<th>Coke</th>
<th>Wood</th>
<th>Heating Oil &amp; Kero.</th>
<th>Gas</th>
<th>Electricity</th>
<th>Other</th>
<th>Total</th>
<th>% Share for Briquettes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1963/64</td>
<td>103.3</td>
<td>4.6</td>
<td>87.7</td>
<td>29.5</td>
<td>71.0</td>
<td>92.7</td>
<td>6.9</td>
<td>395.7</td>
<td>26.1</td>
</tr>
<tr>
<td>1964/65</td>
<td>115.4</td>
<td>3.0</td>
<td>82.5</td>
<td>36.8</td>
<td>72.5</td>
<td>101.6</td>
<td>11.2</td>
<td>423.0</td>
<td>27.3</td>
</tr>
<tr>
<td>1965/66</td>
<td>106.5</td>
<td>2.0</td>
<td>82.8</td>
<td>46.2</td>
<td>71.0</td>
<td>102.5</td>
<td>11.3</td>
<td>422.3</td>
<td>25.2</td>
</tr>
<tr>
<td>1966/67</td>
<td>108.5</td>
<td>1.8</td>
<td>66.1</td>
<td>57.1</td>
<td>76.4</td>
<td>110.2</td>
<td>12.5</td>
<td>432.6</td>
<td>25.1</td>
</tr>
<tr>
<td>1967/68</td>
<td>107.9</td>
<td>1.6</td>
<td>54.6</td>
<td>66.0</td>
<td>78.4</td>
<td>115.4</td>
<td>19.5</td>
<td>443.4</td>
<td>24.3</td>
</tr>
<tr>
<td>1968/69</td>
<td>113.7</td>
<td>1.5</td>
<td>56.8</td>
<td>89.4</td>
<td>87.1</td>
<td>128.7</td>
<td>32.2</td>
<td>509.4</td>
<td>22.3</td>
</tr>
</tbody>
</table>

* Deputy Commonwealth Statistician, Victoria - Factory Statistics

Electricity Supply Association of Australia Annual Statistics
Joint Coal Board Annual Reports
Petroleum Information Bureau, Oil and Australia
Gas & Fuel Corporation Annual Reports
Victorian Forests Commission Annual Reports

Upon appraising the various aspects of the industry it became obvious that its complexities made the adequate understanding of the business extremely difficult. Despite this complexity decisions had to be made concerning what role the briquette industry was to play in future years and the deployment of resources over those years which would maximise earnings. This was precisely a situation where the mathematical model could contribute uniquely in assisting management insight and appreciation to an otherwise intractable situation.

However, before outlining those aspects leading up to the development of the model it may be useful to have a general picture of the briquette industry. Figure 1 below is a diagrammatic representation.
Figure 1. Diagrammatic Arrangement of the Briquette Industry

The figure is divided into the classical areas of raw material acquisition, production, storage, distribution and demand. In the development of any and all models it is the accurate replication of the elemental building blocks which provides the foundation upon which validity of the total model rests. The functional areas listed above were selected for this study as appropriate elements.

The decisions which faced management (and led to the development of the model) involved risk, uncertainty and variability. In the long term the questions were:

(a) For what period of time would the industry contribute to the well-being of the consumer body as a whole?

(b) What would be the industry's earnings over any period?

In the short term the questions were of more immediate consequence:

(c) Should one or two production complexes be operated?

(d) Were modifications to plant necessary?

(e) Was the handling equipment of sufficient capacity?

(f) Were adequate storages available and were these storages located in the best places?

(g) Were the channels of distribution the most suitable and the distribution facilities adequate in various situations.

(h) Were the price levels to the various markets appropriately set giving due regard to customer equity, total consumer benefit and the viability of the industry?
Through the medium of the model, answers to these questions could be obtained. The answers in all cases were expressed in marginal and average terms and used in each strategy evaluation where appropriate.

2. THE SELECTION OF A SUITABLE MODEL

The way in which uncertainty pervades the whole business (and therefore pervades a model replication) limits the use of direct optimising models, e.g., linear programming (LP), queueing models, inventory models, etc. For example, in the briquette industry to search for a long term strategy, the dynamic nature of the business must be known or estimated. An LP that does this but treats uncertainty aspects by simply using average values is not likely to yield a good strategy especially where the interactions between hourly events are critical in the performance of the industry.

By contrast, dynamic programming models can analyse problems to be evaluated over consecutive periods which contain uncertainties. However, dynamic programming in practice can treat only drastically simplified systems for unless the system is characterised by only a few state variables, the computational task of solving a dynamic programming model is beyond the capacity of most computers in use. This limitation is applied in an even more stringent way for dynamic probabilistic models.

The combined effect of uncertainty and risk, the interactions between decisions and subsequent events, the complex interdependencies among the variables of the business and the need to look at hourly events makes the total system problem too big and too intricate to handle by methods outlined above. The best operational research approach in these circumstances is the digital computer simulation.

In this method the uncertainties, decision interactions and interdependencies are formulated and written into a computer program. The simulation of the business begins at a specified starting state and the combined effects of decisions, predetermined and random events cause the system to move to another state. Dependent upon the particular system there will be an optimum time interval between successive states. To span the total period being simulated it is necessary to monitor and modify many consecutive states.

To obtain sufficient statistical accuracy for reliable decisions a considerable number of simulation runs are usually necessary. However, once a basis is established for a given set of input parameters, it is possible to evaluate the effect of a change of any one parameter by holding all others constant and repeating the simulation process.

The briquette industry simulation model provides management with a systematic approach to decision making, a way which is clearly more desirable than the alternative intuitive "analysis".

8.
The structure of the simulation model representing the briquette industry is conveniently described in terms of its dynamic functions and its entities. The dynamic functions are a set of decision rules which are typically expressed as:

What will happen to A if B occurs? These rules are the formalisation of events as they occur in practice. In many studies rules cannot be changed, in this exercise however the model was sufficiently flexible to permit rule manipulation and hence determine the optimal way (within the practical constraints) in which the industry should be run.

The entities of the briquette industry are the previously defined building blocks of production, storage, distribution and demand. Building blocks are composed of many attributes, e.g., consumer behaviour, plant throughput, equipment capability, coal quality, etc. Each of these attributes is ascribed a mean value and a variability. The mean value describes the average performance of the attribute whilst the variability indicates the way in which the attribute value varies in operation.

The complexity which results on putting together these building blocks arises in part from the number of blocks but mainly from the interdependencies of the various parts. Figure 2 illustrates the static framework which describes the structure of the briquette industry.

![Figure 2. Structure of the Briquette Industry-Closed Loop System](image)

In Figure 2 the industry representation is shown in a static form, i.e., the time dimension has not been included. This introduces further complexities of even larger scale and is to be pursued later (Section 5). The figure is also depicted as a closed loop system with only three input values connecting this system to the environment. Although a rudimentary presentation, it permits the model to retain a significantly valid representation of the industry without becoming too large and thus losing the ability to obtain computable answers. For this reason it is also necessary to initially develop the model as time invariant, introducing the time dimension to the model after all the separate entities have been arranged as a total model. The full effect of the interactions within the model are then, and only then, realised.
Whilst the business in its total form essentially exhibits the state of a closed loop system (Figure 2), if more than a few variables exist it is extremely difficult to develop a model from the macrostructure. It is necessary to break the problem down to smaller elements (the entities) and analyse each separately, building up a "block" for later synthesis to the total model. As the entities previously described have clearly defined boundaries they do constitute obvious areas for concentration. The macrostructure in Figure 2 is reproduced in Figure 3, indicating how a set of open loops (the building blocks) do form the closed loop of Figure 2.

![Figure 3. Structure of the Briquette Industry- Sequence of Open Loop System](image)

It is perhaps a better representation, for those loops left open are in the main time-dependent and cannot function properly until the system is brought together as a coherent whole (Section 5). The remaining part of this section will concentrate on the detail of the development of each of the four building blocks.

4.1 Demand

Tables 1 and 2 indicate the type and size of the various markets. The demand in each market is clearly governed by different determinants. Each will be developed separately.

4.1.1 Domestic

Demand in the domestic market arises from the need for home heating and domestic hot water. The hot water load provides a base demand and the heating load the variable demand dependent upon the season. All domestic demand is satisfied through briquette distributors who hold virtually no stocks but order in anticipation of sales.

This set of circumstances allowed a forecasting model based on causality to be developed - the causal factor being that used by fuel merchants as "how cold it is" or more scientifically as used by the model as a function of temperature. Having established a rationale it was then necessary to compile the available statistics in a meaningful way. In terms of sales volume the briquette distributor's turnover is the aggregate
of the purchases made by the end consumer. The daily consignment statistics to distributors were therefore used as the dependent variable after adjustments had been made to allow for the various preferences to have consignments placed at a rail siding on a particular day.

Several independent variables were processed by non-linear multi-regressional analyses to arrive at the best form of the forecasting model. (This form being dictated by the best level of significance of the dependent variable associated with least complexity of the model.) One independent variable, an exponentially weighted function of temperature, was found to satisfy these requirements.

The following factors were used in or influenced the form of the model:

* The living habits of the consumer population being normally distributed about a mean value of comfort.
* 70°F is the criterion of comfort (in terms of temperature).
* Weekly purchasing habits are a norm of consumer behaviour.
* Purchases made over several weeks preceding the immediate purchase decision and the climate conditions expected in the future influence the magnitude of any purchase.

The equation expressing this behaviour was of the form -

\[ Y = \frac{1}{A + BC^x} \]

Where \( Y \) represents the daily domestic demand of briquettes in tons;

\( \frac{1}{A} \) represents the maximum daily demand;

\( B \) is a factor representing a learning curve effect of past and future climate on sales volume.

\( C \) is a factor representing the variability of consumer habits of the population.

\( x \) represents the seven-day moving average of degree days based on temperature statistics of Melbourne.

The form of the domestic forecasting model is shown in Figure 4. The fundamental equation of relationship derived by least squares analysis revealed an acceptably low standard error of estimate, and a high degree of correlation between daily sales and the moving average of daily degree days.
Demand in the industrial market arises from industrial heating and/or process steam requirements. It is dependent upon the cost of fuel, capital cost of plant, modification, operation and maintenance costs of plant. The industrial buyer is essentially an economic buyer.

Owing to the variety of ways in which each of the determinants listed above could affect different customers, a general form, or model, satisfying each customer could be extremely cumbersome. A closer analysis revealed that 6% of customers accounted for 92% of industrial sales. Individual analyses of the customers in this group were carried out and their requirements for briquettes and susceptibility to competition determined. These demands were in terms of their mean value, the variability of their daily purchases being obtained from past records.

The last 8% of customers consuming whole briquettes were trended from records of past data using least squares analysis. Both mean values and daily variability were obtained.

Arising from the manufacture and handling of briquettes, a certain amount of wastage is obtained. Some of this wastage can be recirculated in the manufacturing process and rebriquetted. However, a large quantity must be either consumed by industry or used in the power stations.

The harvest of wastage was projected over the period of planning, sales were estimated to industry and the balance allocated to power stations. The variability associated with sales affected only the amounts going to the respective demand areas.

Char possesses unique properties as a source of industrial carbon of high purity. It is to be expected that a considerable demand will exist; however, as at present it is in the development phase, market performance is non-existent. In this situation market research is the only means of predicting future sales.

In the domestic forecasting model demand was associated with causality, i.e., a reason for purchasing was sought and demand was (statistically) associated with that reason. In the industrial forecasting model a type of adaptive model was used. A trend was obtained and modifications to this trend line were carried out taking into account the particular circumstances of each major consumer. To forecast the char market is far more difficult. Daily variability does not constitute the major problem as in the two methods above; it is the uncertainty that sales will eventuate.

* By carbonising briquettes with a closely controlled heating cycle, the volatile component of the fuel is removed, leaving a strong solid residue (char). This product possesses characteristics which are in high demand as an industrial carbon.
In this situation market research provides the only means of gauging the future level of sales. Local and overseas markets were surveyed and intending manufacturers interviewed. Their plans (checked against market potentials) formed the basis of the forecast model for the char market. The continuous nature of the char making process eliminates any daily variability, although the expected level of sales contained a considerable degree of uncertainty.

Owing to the nature of its demand, however, the char market forecasts could be treated differently to the other forecasts. It affected only the level of production and not the daily variation. The level of sale was therefore used as a parameter in the simulation, not as a variable.

To each of these (static) models was superimposed a secular trend which was determined from consumer surveys and analyses of past statistics. This allowed the forecast models to predict forward any planning span required.

A flow diagram of the forecasting model for demand is shown in Figure 5.

![Figure 5. Flow Diagram of Forecasting Model](image)

### 4.2 Production

As the entire industry was presented in diagrammatic form earlier (Figure 1) a similar representation of the production entity to be modelled may also prove beneficial to the reader. Figure 6 represents the major functions within any of the factories.

The briquetting process takes about $3\frac{1}{2}$ hours. After crushing and screening, fine, moist brown coal is passed through large, steam-heated, revolving drying drums to reduce its moisture content.

This dried coal is screened and the larger particles crushed. It is then cooled in special cooling houses.

Briquettes, extruded through forms, forced out from the presses along narrow troughs - known as launders - emerge in bars containing several briquettes joined together. As these bars reach the end of the launders, they are cut into separate briquettes.
Passage along launders and conveyors allows the briquettes to cool off before being delivered into a specially ventilated storage shed or loaded into Victorian Railways trucks for despatch to other parts of the State. Briquettes for char making go direct to a processing source by belt conveyor.

Throughout this flow path 310 major items of plant are used. These plant are subject to various scheduled and unscheduled outages. In developing the production model all relevant statistics were assembled and the respective frequencies of particular plant downtimes obtained. These are shown in Figures 7 & 8.

In addition, presses must be regularly taken out of service for retooling. The frequency of retooling is dependent upon form life, the variability of which is illustrated in Figure 9. In the program, press outage due to cascading of worn forms is avoided by continually seeking an optimal form life.
Apart from these constraints to plant operations the quantity and quality of the coal and steam affected production levels and the decisions arising from the applications of the rules. Their variability is shown in Figures 10 to 13.

![Figure 10. Coal Moisture](image)

![Figure 11. Coal Quality](image)

![Figure 12. Coal Shortage](image)

![Figure 13. Steam Shortage](image)

In contrast to the uncertain environment of demand the production function could be quantified within stringent probability limits. This mathematical approach combined with a set of decision rules facilitated the development of the production model.

The set of decision rules under which the factory operated (and therefore which governed the form of the model) centres about several factors of production. These were:

* the daily moisture variation in the coal;
* the quantity and quality of coal at each factory;
* the quantity and quality of steam at each factory;
* priority rating for type production;
* drier breakdowns and outages;
* plant breakdowns and outages;
* press form life;
* press outages;
* routine maintenance programs;
* plant shutdown;
* industrial unrest.

Figure 14 illustrates the flow diagram of the production model.
Figure 14. Flow Diagram of Production Model
4.3 Storage

The seasonality of demand for briquettes is shown in Figure 15. This seasonality imposes a necessity to hold stores or back-up production facilities. Owing to the cost escalating nature inherent in the production complex, storage presents the most economical way of augmenting production to match demand and supply.

Briquettes stored are of the industrial type owing to their greater resilience to weathering without a significant loss of quality. Storing industrial briquettes, however, introduces a production priority rating as the daily demand for domestic briquettes must be met ex production. This multi-product situation serves to further complicate the interdependency between production and storage models.

Figure 15. Seasonality of Demand

Figure 16. Supply and Demand

Figure 16 shows the way in which production varies over the duration of one year due to operational procedures. The aggregate sales curve (from Figure 15) is also shown. The area lying between these two curves represents the major stock movements which are necessary to satisfy demand over the period. On any particular day, however, the daily balance of demand to supply determines what will be placed into or drawn from store. This aspect is discussed more fully in Section 5.

Storages located in the near vicinity of the production complex are clearly desirable. This follows from the cost of capital tied up in stocks at the manufacturing site being less than the cost of a similar quantity of briquettes at a site distant from the factory and the occasional inability of production to supply the local market at the works. However, some stock must be held at the market distant from the factory to cover contingencies which may arise from the distribution system. The size of the total holding is dependent upon the shortfall of production to demand over the winter period and the reliability of plant at that time.

The flow diagram of the storage model is shown below in Figure 17.

The model allowed the establishment of stringent control limits and priorities for placing and discharging from particular storage areas on a daily basis. In this way the optimal manipulation of storages was determined.
4.4 Distribution

From the loading sheds at Morwell, briquettes are consigned to private sidings and some 200 public rail sidings throughout the State. Briquette distributors take delivery from these sidings and supply the end consumer.

Using a transportation model the selection of the best use of sidings by particular briquette distributors was made. The transportation model is a deterministic model which searched for the optimal placement of briquette distributors. Supply to these sidings was dependent upon production, storage levels, equipment operation between the plant and outloading point, and the Victorian Railways facilities and timetable.

The available facilities of the VR imposed major constraints on a set of otherwise feasible alternative strategies. It constrained the optimal strategy because of several factors.

These were -

* number of rail wagons available to the industry at any point in time and where these wagons were available;

* turn-around time of rail wagons;

* line capacity;

* other VR business, e.g., wheat, super phosphate, etc.

* freight timetable;

* locomotive availability;

* siding capacities and daily variability.
The simulation was run with and without these constraints and at certain intermediate values to determine the best strategy to follow. The sensitivity of each of the constraints (above) was evaluated as was the cost of making each alternative workable given the particular constraint setting.

The flow diagram for the distribution model is shown in Figure 18.

![Flow Diagram of the Distribution Model](image)

5. THE LOGISTIC SYSTEM

The concept of a logistic system is generally recognised. It implies the efficient management of the flow of materials and products from source to user. It has become accepted that there is a need to design and manage a business as a single unit rather than a series of discrete, independent functions.

This concept applied to the briquetting industry involves the integration of the four entities of demand, production, storage and distribution into an all-embracing form. This form is defined here as the logistic system and is represented by the briquette industry model.

The logistic system is time and event dependent. Any events occurring in entities which hitherto have been treated as disjoint from other entities clearly take on a new and more significant role. The situation is one where everything is dependent upon everything else constrained only by a set of working rules.

Integrating the time domain and the static model brings out the problem of evaluating and selecting the optimum time span between monitoring and modifying consecutive states in the simulation exercise. The optimum time span depends upon the particular event under study and the maximum length of time it may be ignored without significantly affecting the validity of the overall results, for example:

(i) For the demand function the event must be looked at initially to allow production planning for the day and then modified when the actual orders are known. Two states of demand on any day are all that is required.
(iii) The variability of demand and of production on any day may require augmentation from, or dispatching to, storages. The event can occur at any time of the year, not only on occasions when seasonality is demanding a certain mode of operation. It is therefore necessary to monitor stores frequently throughout the day.

(iv) The dependence of the whole works upon the collection conveyors and loading facilities points to the essential nature of their operation. Hourly events are clearly significant. This part of the distribution function is looked at on an hourly basis. In contrast, the VR empty wagon supply is evaluated only once per day, as are the fixed aspects of freight timetable, daily siding usage and wagon turn-round time.

Once time has been brought into the framework of the model, the resulting form assumes a dynamic character. Interdependencies between variables are then further influenced by interactions between events of a time period and the events that precede and follow it. Uncertainty and variability which permeate through the entire model bring out a degree of complexity almost beyond human comprehension. It is a situation where some scientific approach must be used; and the mathematical model contributes precisely this. It can and does provide a sound basis for the effective management of the business.

Figure 19 illustrates the broad aspects of the model.

![Figure 19](image)

Figure 20 shows a typical full output format for a single day which is necessary for evaluating tactical manoeuvres, and Figure 21 illustrates a summarised form used for strategic evaluations.
Modelling of the logistic system throws into sharp relief the areas sensitive to business decisions, be they seemingly insignificant (e.g., form life) or of a major nature (retirement of a factory). The model allows management to concentrate on those areas critical to the efficient running of the business.

6. COST/EFFECTIVENESS OF THE MODEL

The cost of building a model such as this is mainly in the salaries of the staff engaged in its construction. The balance of costs are absorbed by program development and operation of the computer. Development of this model involved some three man-years - this covered the period starting with the definition of the problem to a stage where results for management perusal and action were being obtained. Of the computer costs, 25 hours elapsed time on an IBM 360 Model 40 were spent in developing the program. On the Commission's IBM 360 Model 50 a production run for one year in full output form takes 4 minutes of c.p.u. time. In summarised form it takes $2\frac{1}{2}$ minutes. Tactical decisions are made from the full output mode and rarely extend for more than 18 months. Background to decision making on the tactical front is therefore obtained in about 6 minutes of c.p.u. time for each simulation. On the other hand, strategic decisions are required over a planning horizon of 5-10 years. Each simulation run on this basis takes about $12\frac{1}{2}$ to 25 minutes of c.p.u. time.

The value obtained from this investment could be assessed on two fronts:

6.1 Tactical Control

As a tool to provide a quantitative basis for decision making, the model has been used in many application areas. Examples of these are:

* Optimal level of stock holding by weeks and the areas where these stocks should be held.
* Evaluation of emergency situations and the ability of optimal stock levels to supply these requirements.
* The best use of existing store facilities.
* Production capability required.
* The effect of plant additions or removals.
* Upgrading or degrading of plant capability.
* Optimal maintenance programs and determination of the best times for routine shutdowns and plant maintenance.
* The effect of varying the quality and quantity of coal and steam inputs.
* Establishment of optimal working rules for the factory.
* Elimination of production "bottlenecks".
* Determination of a realistic incremental cost of production.
* The sensitivity of the VR interface with the model.
* Short term sales strategy based on incremental costs.
* Cost relationship between product quality and sales.
* Areas for intensive sales promotion.

6.2 Strategic Planning

In the long term the model quantifies the role of the briquette industry in terms of present worth. The viability of the industry can be brought under intense scrutiny merely by applying sensitivity analyses to critical factors. Such studies include:

* Evaluation of consumer trends.
* The effect of various pricing strategies.
* Desirability of capital investments.
* New market penetration.
* Competitive activity.
* Variations in cost structure.
* Product development.
* Variation of personnel numbers.

The model provides management with a tool that can evaluate any set of input conditions. It gives management a quantitative base for decision making.

7. ACKNOWLEDGEMENTS

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More and more organisations are discovering that the best use for a computer is in the areas of strategic planning rather than attempting to reduce staff by the computerisation of relatively mundane processes. The attempts to reduce costs by using the computer as a "super-clerk" often have the reverse effect replacing relatively unskilled personnel with expensive computer scientists.

This situation also reduces the organisation's flexibility, both in the day-to-day running of the company and in making changes such as the introduction of new products and amendments to pricing strategies.

On the other hand there are an increased number of successful computer applications in such areas as :-

Transport planning - where the savings accrue from reduced vehicle mileage, resulting in lower fuel bills etc. and higher utilisation of the existing vehicles.

Production control - where machinery redundances and overtime payments are reduced.

Inventory management - where reduced stocks can result in reduced capital maintenance and warehousing costs.
Planning - which involves forecasting on a short-term basis. For example, quarterly sales forecasts and, on a long term basis, technical forecasting and annual market growth rates. Both areas can direct the company's operations into more profitable markets.

It is true such types of computer usage require skilled personnel and are expensive. However, these applications of computer methods can be investigated reasonably thoroughly before implementation. This can be done by applying the methodology to a representative sample or section of the operations which can often be achieved by using current or historical data.

This paper discusses an application of computers to transport planning and particularly the scheduling of truck fleet operations. This aspect of transport planning has been investigated for many years resulting in the development of computer techniques which are readily available to any organisation in the form of software packages for generating vehicle schedules. The principal benefits from using the packages include:

- reduced fleet mileage
- reduced work time and wage bills
- higher utilisation of vehicles
- improved customer service
- more detailed and accurate fleet control data

A typical example of possible savings can be demonstrated by considering a fleet of 10 vehicles being used in country areas in Australia. Each vehicle might cover 100,000 miles each year at a variable running cost of 30 cents per mile. The total cost for the 10 vehicles would be of the order of $300,000 a year. The use of vehicle scheduling by computer could reduce the mileage by 5 to 10% which would result in a cost saving of $15,000 - $30,000 a year. This reduction in mileage could also lead to a reduction in overtime of between $2 \frac{1}{2} to 5\%.$
More systematic scheduling of vehicle fleets whether by computer or manual means will usually reduce transportation costs, provide control data, but of ever greater importance will provide management with a flexible planning model of their truck fleet operations.

When Can Computers be Used for Truck Scheduling

There are four basic conditions, all of which should be satisfied before attempting to utilise computer vehicle scheduling. They are as follows:

1. The distribution system should consist of a central depot servicing at least one hundred delivery points.
2. All vehicles in the fleet should return to the depot after they have made their final call.
3. The fleet should contain more than five vehicles.
4. The average delivery (or collection) should be less than the vehicle capacity.

In fact the expected savings from computer vehicle scheduling can be expected to increase as the average number of drops per trip increases. A typical example of a distribution pattern that would benefit from vehicle scheduling is petrol tankers that load at a particular refinery and deliver a number of grades of fuel to service stations returning to the refinery after the final call has been made.

Methods of Generating Current Truck Schedules

There are two fundamental methods of organising schedules. These depend on the availability of a computer and the variability of demand. Both methods can provide extremely useful planning data. The two methods are:

1. Random orders - this system is used in an organisation where orders are received during the day, loaded at night, and delivered the next
day. In this case a new set of schedules is generated at the end of each day so that the optimum use can be made of the available vehicles. The same system may be used over a time scale of a week when new schedules are generated each weekend. This type of system really requires immediate access to a computer. Probably the only solution is to have a machine in-house with back-up from either another in-house computer or from a bureau. This method of application is particularly useful when the demand pattern fluctuates rapidly.

2. Forecasted orders - a system used in a company having a reasonably settled pattern of deliveries when the computer generates schedules on a monthly or even a quarterly basis. A forecast is made of customers' requirements for the coming quarter and these delivery quantities are used to generate a set of schedules or time tables to be used during the forthcoming period. New schedules may be generated for a number of reasons, for example:

- Changes in demand due to climatic conditions or holiday periods.
- Changes in the number of customers.
- Changes in the vehicles available.
- Changes in the road network.

This type of vehicle scheduling can be satisfactorily carried out by a computer bureau and is therefore available to almost any company.
Vehicle Scheduling is Effective in Both Urban and Rural Areas

Vehicle schedules generated by computer have been used in both urban and country areas. Schedules for urban areas have been developed in Melbourne by a large oil company, and in Western Australia they have been generated for use in rural districts, encompassing the whole of the southern half of the State.

Over the last five years computer generated vehicle schedules for trucks, aircraft, barges, ships (tankers and war supply ships) and trains, have been used to distribute or collect steel, crude oil, groceries, beer, L.P. gas, petrol, heating oil, various types of ore and people e.g. couriers, soldiers and air crews.

The following is a list of examples :-

1. Groceries to supermarkets (this was the earliest use of computer vehicle scheduling)
2. Delivery of home heating oil
3. Collection of cheques from branch banks
4. Servicing of bottled gas installations
5. Collection of children by school bus
6. House calls by doctors
7. Forklift trucks within a warehouse
8. Distribution of pay from the head office of a company to its branch offices
9. Mobile canteens to construction sites
The Theory of Computer Packages

A number of different solutions have been formulated for various types of scheduling problems. The solutions have employed such techniques as linear, integer and dynamic programming, branch and bound, combinational programming and heuristic algorithms. Most of these methods guarantee an optimum solution, however many of them are limited to particular situations and in many cases can only accommodate problems of limited size.

A less rigorous algorithm has been developed by Clark & Wright\(^{1}\) which is readily adaptable to computer methods. It also permits the inclusion of many of the refinements, such as assigning particular vehicles to particular customers, required to generate practical schedules.

This algorithm and adaptations of it are the basis for all the vehicle scheduling computer software packages commercially available in Australia.

When considering truck distribution problems, three basic sets of data are required:

1. The network of roads connecting all possible delivery points and the depot.
2. Vehicles available to make the deliveries.
3. The set of deliveries to be satisfied.

The generation of vehicle schedules is theoretically a six-step process as follows:

1. Define the depot and the possible delivery points including the specification of the distances between each pair of points within the network.
2. Select each pair of delivery points in turn and "the savings" are calculated for each pair. The "savings" are defined as the savings in time or distance between delivering to two customers independently, i.e. a total distance of $2a + 2b$ (see Figure 1), compared with making a round trip to two customers, a total of $a + c + b$. The "savings" are defined as the difference between the two journeys, namely $2a + 2b - (a + b + c)$ giving a savings of $a + b - c$.

3. Sort the list of savings into descending order of importance; this list or file of savings remains constant throughout the scheduling operation, and is only readjusted for the inclusion of new distribution points or the inclusion of new routes. This process of developing the savings file is usually referred to as "Network Analysis".

4. Define the vehicles to be used in the schedules - the capacity of each vehicle available must be defined together with such parameters as the length of the working day of each vehicle and its average speed.

5. Define the deliveries to be made in terms of where they go, how much is to be delivered and any data concerning restrictions about deliveries such as the times when the customers premises may be closed or unable to receive deliveries.

6. Select the first pair of deliveries that appear on the savings file, hence achieving the maximum time or distance reduction, (Computer packages use the reduction in time when calculating the savings). This pair of deliveries should be allocated to the largest vehicles which normally go on the longest routes. The next pair of linked deliveries should be selected from the savings file.
FIGURE 1
DEMONSTRATIONS OF SAVINGS

Savings = (2a + 2b) - (a + b + c) = a + b - c
These should also be allocated to the first vehicle assuming that there is sufficient capacity to contain the load. This procedure should continue until the first vehicle is fully loaded and so on.

The procedure is completed when either all the orders have been satisfied or all the vehicle capacity utilised; if there are any outstanding orders at this stage they will normally be listed in some way so that an indication of further vehicle requirements can be made. This procedure is normally referred to as the "Schedule Production".

The commercially available vehicle scheduling packages all use this two step process of generating a network which is available for a number of different schedules, and the second stage is the generation of schedules listing which deliveries should be carried out by which vehicle, and the order in which the vehicle should make its particular deliveries.

There are Three Commercially Available Computer Vehicle Scheduling Packages

Two of these packages are marketed by ICL and the third by IBM. The first entitled "Vehicle Scheduling (tape/disc) Mark 3", which is the result of some years of development by ICL. The second entitled "Vehicle Routing and Fleet Planning" was developed by English Electric-Leo-Marconi and subsequently incorporated within ICL to be used on System 4. This package has not had further developments. The third package entitled "Vehicle Scheduling Program" (V.S.P.) was originally developed for the 7094 by IBM and has been updated to run on System 360 and further updated during 1970, the new update entitled "VSPX".

Details of these three packages are given in the Appendix.
Fleet Planning

The benefits from establishing a model of an organisation's truck fleet operations are very often twofold. Firstly, as noted earlier, the use of scheduling procedures can reduce the day-to-day operating costs by 5 to 10%. However, probably the more important benefits are achieved by utilising the already established scheduling device to assist in the problems of strategic fleet planning. In fact in some cases it can prove worthwhile to establish a model of the fleet operations by means of a computerised vehicle scheduling package solely for planning purposes.

This type of model allows for a number of aspects to be evaluated, the following are discussed in this paper.

- The selection of the location of new depots
- The selection of replacement vehicle types
- The establishment of economic delivery frequencies

How to Select Depot Locations

One of the most important decisions affecting a vehicle fleet is the position or location of the depot or depots. In many companies these are already established and would be extremely difficult to move, especially when depots are associated with production facilities. However, expansion or decentralisation can provide the need to re-establish an existing delivery depot or establish a new one, and the penalties for misplacement can be considerable. It must be realised that the selection of a depot site is based on many variables including such factors as the availability of suitable land and availability of labour. However, a good starting point can be established by finding that location or district which would minimise the distribution costs in the coming years.
This confidence in the location decision is achieved with the help of market and technical research. It is possible to define the typical delivery quantities that might be expected in the coming years and from an analysis of the geographical distribution of customers it is possible to establish a reasonably acceptable future distribution pattern.

The next step is to select a depot site which from a general consideration would appear to be a reasonable location. Then select a fleet of vehicles, either the present fleet or the expected fleet in the near future and generate the schedules of deliveries to the predefined customers with the selected fleet. These schedules are then costed in terms of the expected labour rates and vehicle mileage costs, hence evaluating the costs associated with the particular location. The depot is then "moved" to another suitable location and the procedure repeated and the costs compared with the original cost. This procedure can be carried on for a number of different locations (the use of a computer programme will facilitate the calculation) and contours of equal cost can be plotted on a map. This map provides management with very useful information when comparing the pros and cons associated with different possible depot locations.

This method of depot selection can be further sensitized by reviewing the effects of changes in demand patterns and possible customer locations. It can also be used to determine the demand pattern that would justify the establishment of a new depot in, for instance, the outer suburbs of a large urban centre. The new depot may be supplied by the primary production point by some form of bulk shuttle service and a new fleet established at this depot or a new production plant established. In either case a very similar approach can be adopted to assist in the strategic planning.

**How to Decide on Fleet Composition**

All fleet managers have the problem of selecting the most suitable vehicle types and the most economic timetable of acquisition. New vehicles are required because of replacement or because of increasing demands.
Normally there is not an infinite selection of suitable vehicles available and the management has to make a decision within a limited number of vehicle types. They also have the problem of selecting expensive durable vehicles compared with cheaper, possibly less reliable vehicles. They have to use their experience to offset the costs of maintenance against the initial capital costs. This type of decision is very much a question of experience and knowing the terrain and the area in which the vehicles are to be used. However, there is great scope for planning the capacity of the vehicle or vehicles that are required, whether they should be compartmented, and what sort of unloading equipment might be attached to the vehicles.

If we consider for instance the type of vehicle acquisition caused by increases in demand, it is possible to generate forecasts of future requirements and to make some estimates of the possible locations of these demands for the company's product.

A vehicle scheduling software package can be used to simulate the delivery of the forecasted demands and the costs associated with any particular vehicle type can be evaluated together with the total costs of the distribution activity.

It is then possible to select a type of vehicle that is thought might be the best to incorporate in the fleet and reschedule these same deliveries with the new vehicle or vehicles included in the fleet. The resulting schedules can then be costed and compared with the costs associated with running the existing fleet.

Some considerations of maintaining the same level of customer service in the different types of schedules must be borne in mind throughout the exercise.

The next step in the process is to generate a new set of schedules with a new selection of vehicles to augment the existing fleet. This procedure can then be carried out as many times as required and the costs of the resulting schedules evaluated; hence demonstrating to management the effects on the distribution costs of the various types of vehicles.
A preliminary investigation often shows that a fleet with the largest types of vehicle possible is one which minimises transportation costs.

However, this may be impractical especially if there are a lot of deliveries in congested urban areas or where it is impossible to deliver to all customers with the larger vehicles. Hence, there is the problem of selecting a mix of vehicles that is suitable for the particular distribution pattern. This can be achieved by utilising the various options, provided within the computer packages.

The results of this type of analysis will depend on the forecasts of customer requirements and customer locations as in the case of depot siting it is possible to carry out sensitivity analysis and demonstrate the effects on fleet costs of varying demand patterns. This type of information is valuable both in the decision making stage of selecting and purchasing new vehicles and also in establishing operating budgets.

Determining The Frequency of Delivery

In the situation where the transport operator is delivering to customers on a regular basis costs can be reduced by a review of the delivery frequencies.

If deliveries are made too frequently the transport costs will be high whereas the costs of holding the product at the individual customer or outlet locations will be lower since the average stock held will be quite small. In fact the average stock is equal to half the average consumption during the period between deliveries plus some degree of buffer stock.

On the other hand if deliveries are made very infrequently the transportation costs may go down drastically but the stocks that must be held at the individual delivery points will be increased. There is obviously some compromise between the two extremes that gives a minimum total cost. It is possible to use vehicle scheduling packages to determine the economic delivery frequency to customers in the following way.
Firstly an estimate must be made of each customer's usage. This may vary from season to season so that it is necessary to have different frequencies at different times of the year. The schedules are generated using a computer package and then costed for a number of various frequencies.

For instance cost may be calculated on frequencies of one, two, three and final four weeks. The associated transportation costs can then be very quickly and reasonably accurately forecasted using the package.

A model must then be used to determine the stockholding costs associated with each of the frequencies and a graph similar to that shown in Figure 2 plotted to help determine the minimum cost frequency. A further extension to this methodology is to be able to accommodate a number of different frequencies within a set of schedules. Thus the customers with greatest demand often receive more frequent deliveries. On the other hand customers or outlet points with somewhat less than average demand receive fewer deliveries. This method does not guarantee the optimum solution but is often a very useful way of giving confidence to decisions and changes in distribution methods and allows for the determination of the costs of these changes. This type of cost information can be invaluable when comparing various levels of customer service and when evaluating particular marketing strategies.

Conclusions

In a study carried out last year in Western Australia it was shown that such types of vehicle fleet planning procedures are applicable in both metropolitan and country areas. There are a number of examples of computer models for distribution in metropolitan areas and in outlying suburbs both here and overseas.

However, this study demonstrated the use of these techniques in planning distribution strategies in the rural areas of Australia, where the widely dispersed population centres generate unique problems.
FIGURE 2

DETERMINATION OF THE ECONOMIC DELIVERY FREQUENCY

![Graph showing the relationship between basic delivery frequency and costs]

Total Costs

Distribution Costs

Storage Costs

Basic Delivery Frequency in Weeks
In order to consider the application of these types of planning and operational control methods it is necessary that there are at least 100 delivery points and a fleet of more than 5 vehicles. Also the ratio of the average dropped to the average capacity of the vehicle should be in the range of 1 - 20 to 1 - 5 and the distribution operation must be of a form where the vehicles return to the depot after each trip. These methods are not applicable to the long-distance haulier who may be picking up and delivering in the same route. This presents a far more complex set of decision rules and normally each case must be considered by a quite separate methodology.

The benefits of planning suitable distribution operations with computer models can be a reduction in cost between 5 and 15%. The other advantage of carrying out this type of investigation is that many of the hitherto unknown variables become rationalised providing a clearer picture of an otherwise complex problem.

The use of fleet planning models can be used to advantage in the two types of scheduling procedures, the first of which is the 'random order' method where new schedules are generated each day or each week. This is suitable for companies that have access to their own computer or extremely good access to a bureau machine, especially for the day-to-day scheduling.

The second method of using these fleet scheduling models is the generation of 'forecasted timetables' where a set of schedules are used for a number of cycles and may be in operation for months or even a year at a time. New timetables are only generated when relatively large changes in the total system occur.

We have shown three areas where fleet scheduling not only provides us with a practical day-to-day tool but also with a strategic planning and :-

- In the evaluation of depot location where there can be large costs savings in establishing the depot at the right point within the distribution network.
In making long term decisions on the composition of the fleet. They allow the means of comparing the costs of using different types of vehicles, in particular parts of the network or demonstrating the most economical way of expanding the existing fleet's capacity.

In determining the economic frequency of delivery by offsetting transportation costs against stockholding costs. This situation has been investigated for an Australian company where retail agents are established in most of the small towns outside the metropolitan area and supplied by bulk vehicles. By determining the economic delivery frequencies it was possible to reduce costs by 10%.

The planning aspects of computer packages are available to anybody through the use of bureaux. However, some experience is needed in their successful application. Where possible a pilot study should be undertaken to determine the economic viability of pursuing these methods. In practically all of the cases it is found to be more economical to use the existing standard packages.

However, in certain circumstances there is justification in writing a new set of programmes to satisfy an organisation's particular needs. Again the use of existing packages to determine the viability of this course of action is a recommended procedure.

These particular requirements may be caused by the distribution problems or the fact that the organisation already has a particular type of computer and the delivery information is available in a particular form and hence there are benefits in producing a special truck scheduling computer programme.

An added advantage of the implementation of computer vehicle scheduling is that the company has less reliance on one or two people's experience and the distribution costs can be controlled in the absence of a highly experienced scheduler.

However, the greatest advantage of vehicle fleet planning comes not in the day-to-day tactical planning of operations, although this is very valuable, but in the strategic planning for such areas as selecting depot locations, fleet composition, and economic frequency of delivery.
DETAILS OF COMMERCIALY AVAILABLE
COMPUTER SOFTWARE PACKAGES
FOR VEHICLE SCHEDULING

There are three packages currently available in Australia, they are:

ICL - Vehicle Scheduling (tape/disc) Mark 3

ICL - Vehicle Routing and Fleet Planning

IBM - Vehicle Scheduling Program Extended

The above are reviewed under the following headings:

1. Size - the number of delivery points and number of
   different types of vehicles that can be accommodated
   by a particular package.

2. Delivery Points - the number and type of restrictions
   which can be imposed on delivery points.

3. Vehicles - the methods of defining their capacities
   and speeds etc.

4. Input - the facility of a package to accept data from
   existing files and the ease with which data can be
   prepared.

5. Output - the ease of interpreting the output from the
   computer packages and the ease with which they can
   be incorporated with existing data files.

There are at least another ten packages being marketed overseas,
some of which are likely to be available here quite soon. In fact
both Honeywell Pty. Ltd. and National Cash Register Co. Pty. Ltd.
intended marketing vehicle scheduling packages in Australia within
the next twelve months.
ICL - Vehicle Scheduling (Tape/Disc Mark 3 - 1900 Series)

This package has recently been updated and the new version is based on a control language similar to ALGOL and is very much orientated to fitting in to an organisation's existing file structure. The package is written for the 1900 series with a minimum configuration of 32K words of core store, a card or paper tape reader, a line printer and five magnetic tape decks or two exchangable disc storage cartridges.

Size - the size of problem that can be accommodated by any package is very much a function of the size of computer. This package has been used to schedule deliveries to three hundred delivery points, however, this is by no means the maximum size of problem even when utilising the minimum computer configuration.

Delivery Points - The delivery points to be covered by the vehicle schedules are defined in terms of grid references. These references can be based on a national system or on a user defined set of grid lines. There is a third method of defining the grid which consists of subdividing the area to be covered by the schedules into squares. Each square is numbered and the user must specify the number of squares and the length of the side of each square. The distances between delivery points and each depot are calculated from the formula -

\[ \text{Road Distance} = A \cdot D + B \text{ where } D \text{ is the straight line distance between two points and } A \text{ and } B \text{ are constants set by the user.} \]

The straight line distance between two points is calculated using Pythagoras Theorem. The factors A and B depend on the type of country, i.e. rural, urban, flat or hilly, but unfortunately must be constant for the complete network under review.

This package contains the facility to define "Barriers". These Barriers are defined in terms of their two end points; they represent a straight line over which it is impossible for any route to pass. However, it is possible to specify pass points at the end of each Barrier, i.e. points that can be used such as bridges over rivers.
The package also provides for the definition of "Congested Areas", these areas represent districts where the average speed of vehicles is reduced to a level pre-specified by the user. This facility is useful when routes are expected to pass into urban areas and then back into comparatively faster moving rural districts.

There are four restrictions or constraints which can be specified for each customer. These constraints are taken into account when schedules are being generated. They are as follows:

1. The normal delivery times for each customer, i.e. the most acceptable time to make deliveries.
2. The definition of the early closing days associated with a particular customer.
3. The maximum vehicle size permitted at a customers' premises.
4. Giving certain customers' orders higher priorities than others.

Vehicles - When specifying vehicles there are 8 constraints which may be applied. They are as follows:

1. The maximum length of a route.
2. The maximum time spent driving on any route.
3. The earliest start and latest finish times for routes specified in terms of the time of day.
4. It is possible to specify routes that last two days.
5. The unladen weight of the vehicle for use when specifying particular customer restrictions.
6. The unit cost of travel for each type of vehicle can be specified to assist in the overall costing of schedules.
7. Up to 4 different compartments can be specified within each vehicle.

8. The limiting capacity of each of the four compartments can be specified in terms of two dimensions, for instance weight and volume.

Input - Input to this package can be by punch card or paper tape. It is also possible to use existing customer files and transform them into the format necessary for this package. The programmes contain useful file update procedures both for customers' names and addresses and for the inclusion of new delivery points or depots.

Output - This package, unlike any other on the market, gives extremely detailed output, including the names and addresses of the delivery points. This means that the documents can be used directly by drivers and need no intermediate translation or decooling. The program also provides an inventory of current customers with their names and addresses and it is possible to use this file for preparing mailing lists etc. The package can provide a comparatively easily integrated scheduling system but to date has not been intensively used.

Vehicle Routing and Fleet Planning

This package was developed by English Electric-Leo-Marconi which is now part of ICL. The package was published originally in September 1965 and has not been greatly updated since that time.

Size - The package can handle up to 1,000 delivery points associated with any one depot and can be served by a maximum of 990 vehicles. There is a maximum limit of 128 deliveries in any route. The package can be run on a System 4 computer with 131 Kbytes of core, card reader, line printer and tape facilities are required for particular file options.

Delivery Points - The location of delivery points are specified by means of co-ordinates. The scale and base of the co-ordinates can be specified by the user or use can be made of an existing map reference system.
Distances are calculated by determining the straight line distance between points and multiplying by a factor. The factor is usually found to be in the order of 1.2 but can be specified by the user.

The time a delivery can be made can be specified for either the first half or the second half of a day. There is also an option which specifies that a call must be the first or last call on a particular route. Congested areas (i.e. where speeds may be restricted) can be specified and a slower average speed used within these areas. Natural barriers that exist in the local terrain such as river estuaries can be defined by including data as to the bridge points at which they may be crossed. All routes that have to cross these barriers will be routed with the shortest possible distances through the bridge points. As with all vehicle scheduling packages the package can be used to schedule collections or deliveries, but not both on the same set of routes.

Vehicles - When specifying the constraints associated with vehicles the following are available :-

1. Each route undertaken by a vehicle can be limited by the maximum distance it can travel.

2. The route can be restricted by the number of calls that can be made.

3. The route can be restricted by the total journey time.

4. It is possible to schedule two day trips for vehicles but this must be carried out during a separate computer run.

5. It is possible to have 10 different types of vehicles with a maximum of 99 of each type.

6. Each vehicle can be specified to have 3 speeds, depending on the local conditions within which it is travelling.
Input - Input to this package is by means of punched cards, due to the relative simplicity of the package the accompanying input is easy to compile and check out.

Output - Output from this package is relatively uncomplicated and contains the following values:

- The calls to be made
- The order the calls are to be made
- Most suitable vehicles to be used on each route
- The actual capacity of the vehicles utilised
- The total mileage travelled in each route
- The total time spent on each route

Summary data is provided in the output and includes the total mileage travelled by all vehicles and details of any points or deliveries that have not been assigned. There is no facility for the incorporation of existing files with this package either within the input or output data. However, facilities exist for writing one's own "Head" and "Tail" program; the necessary documentation is included in the manuals.

This package provides a reasonably simple means of deciding on the benefits of using computer scheduling and is the basis for a specially designed programme to meet the particular users' needs. However, further developments are being made on packages for System 4 users. The computer costs are approximately $40 fixed cost per schedule production run plus 3 cents per called point. This package has been used by a large refining company in Australia.
IBM - Vehicle Scheduling Program - Extended

Size - This package can in the extreme handle a distribution pattern containing 2,700 zones, each zone containing a maximum of 255 customers. This size of problem would require an extremely large machine (e.g. 360/65). The size of problem that can be handled with this package depends on the size of core and peripheral equipment available with the computer system as well as the number of options provided by the package that are required by the user. The number of deliveries that can be handled in one set of schedules can range from 700 with a very small computer (the minimum configuration is a 360/30 with a 64K bytes core) to 5300 with the largest type. A maximum of 225 different vehicle types can be specified with an unlimited number of vehicles in each type. However, if the trailer option, see below, is used, only 15 different vehicle types are allowable.

Delivery Points - This package provides two methods of specifying distance relationships between customers. The first method is the co-ordinate method similar to that used in the other two packages. The facility exists for specifying barriers and pass points through which routes can cross barriers, congested areas where the average vehicle speed is reduced, and for specifying the co-ordinates with respect to a standard grid system or a user provided non-standard grid reference system.

The second method of specifying the geographic relationship between customers is to measure and record the true distance along each link joining the delivery points to each other and the delivery points to the depot. The distance of each link can be specified in either miles or kilometers and it is possible to specify a speed associated with each particular link.

The advantages of this second type of network description or specification is that it provides greater accuracy, but on the other hand it is more laborious to collect and set up the data and requires longer computing times to provide the necessary files.
There are at least six options that can be used within this package to specify delivery points. They are as follows:

1. Limited or specific calling times at any customer so that pre-arranged delivery times can be met.

2. Unloading times that are proportional to the quantity of goods delivered or a specific unloading time at any particular customer. It is also possible to define an average duration to make a delivery.

3. The maximum size of vehicle that can deliver to a customer can be specified.

4. An individual call may be limited to a particular vehicle type.

5. Certain calls can be given a low or a high priority rating and removed, or definitely included within a particular set of schedules.

6. Particular deliveries can be specified to be the first or last delivery on a route.

Vehicles - It is possible to specify up to 255 different types of vehicles, each with a different capacity and maximum route time if required. There is a facility for assigning particular trailers to particular vehicles. If this option is used it restricts a number of the other facilities that the package provides. However, there are a large number of options available in this package. The following is a list of the more important:

1. The average vehicle speed can be specified.

2. The earliest starting and latest possible finishing times for each working day can be specified.

3. Vehicles can be specified with up to 15 compartments, each with a different capacity.
4. The maximum route time can be limited with the maximum possible duration of a route being a multiple day route of 22 days.

5. A vehicle route can be limited by the number of deliveries allowed and/or the maximum distance that can be travelled.

6. It is possible to organise the vehicle specification data so that vehicles can carry out multiple journeys in a particular day.

7. It is possible to specify the load in terms of two units such as weight and volume.

Some of the above options are mutually exclusive, and the inclusion of too many in one set of schedules increases the computing time and limits the size of problem that can be handled on a particular computer configuration.

Input - The input to this package is normally by means of punched cards, however, it is possible to write a head program in PL.1 which converts the users format to the form required by the package.

Output - The output consists of three parts, as follows:

1. A list of the options that were requested together with the parameters such as unloading rates, earlier starting time, later starting time, etc.

2. The routes themselves consisting of the customers specified in terms of the customer numbers, the quantity to be delivered, the time of arrival at the customer and the time of leaving the customer. Each route specifies the customers and the order in which deliveries should be made.
3. The final stage of output is a summary of all routes and indicates the fleet utilisation in terms of total distances driven, total quantities delivered, etc. The package provides the output information on files that can be assessed by PL.1 programs and it is possible to generate a customer name and address file and hence generate documentation that may be passed straight to the scheduler or to the vehicle drivers.

Comments

This program has had extensive use overseas. In Australia it has been used by a large oil company in Victoria for scheduling home deliveries of oil, and in Western Australia for scheduling the deliveries of liquid petroleum gas. Other trial runs of the package have been made by companies both in New South Wales and Victoria. This package is by far the most comprehensive and the facility for specifying the network links in terms of their true distance rather than using a grid system is particularly applicable to schedules in rural area.
REFERENCES

(1) Clark G. & Wright J. W. (1964) - Scheduling of vehicles from a central point to a number of delivery points - Ops. Res. 12(4) 568-581.


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INTRODUCTION.

The Australian Gas Light Company has a number of firsts to its credit. Being founded in 1837, it ranks as Australia's oldest industrial Company. In 1955 it installed the country's first non-University computer, and its Operations Research group's 1957 beginning makes it one of longest running local units.

The Company's production methods were steeped in tradition, and it was thought by some production people that no significant economic improvement over tried and trusted procedures could be introduced by the 'nouveau sage'. However, technical, economic and market developments in the industry have occurred so rapidly that their full implication has only been realised and exploited with the aid of scientific decision making techniques.

From a situation where coal was the only acceptable and available raw material for about a century and coke was a commodity in high domestic demand, oil has become locally available as both a raw material and a competing fuel. The last decade has seen the appearance of numerous refineries on the Australian scene, with a whole spectrum of products which are acceptable feedstocks for an increasing variety of available gasmaking processes. The past couple of years has seen the introduction of natural gas into most Australian capitals, and it will be in Sydney in the predictable future. Natural gas can be used either as a feedstock for the manufacture of towns gas in existing plants, or be distributed directly to customers whose appliances have been converted to accept it. During the three year transition period from towns gas to natural gas burning appliances, natural gas will be used as the almost exclusive raw material for towns gas manufacture.

This paper aims to outline some of the ways in which linear programming has been used to aid management decision making during this period of industry evolution. It does not pretend to describe the process in detail, nor is it presented as the latest developments in O.R. at A.G.L., for the philosophy outlined had its beginnings some 14 years ago.

A short section is devoted to an outline of the linear programming technique, and it is shown how the gas production problem is a classic application of L.P. Short summaries are given of instances of its use, and comments are made on its value.
2. LINEAR PROGRAMMING.

2.1 Example

Consider the case of a certain manufacturer who turns out only two products, tables and chairs. Now since there are only two products it is possible to represent any combination of outputs as a point on a diagram as follows:

![Diagram showing the production of tables and chairs per week]

Thus the point P in figure 1 indicates the production of 300 chairs and 50 tables per week.

In planning his weekly production pattern, the manufacturer must take the following restrictions into account.

(a) The machine which turns out chair legs has a maximum capacity of 450 chairs per week.

\[ C \leq 450 \]

(b) The supply of table tops has an upper limit of 100 per week.

\[ T \leq 100 \]

(c) His market knowledge shows that he must produce at least two chairs for every table, but can sell any chairs surplus to this figure.

\[ C \geq 2T \]
(d) He has a labour force amounting to not more than 600 hours per week, and knows that each table requires 3 man hours, while a chair uses up 1 man hour. The total number of man hours required is $3T + C$ which must be less than 600

i.e. $3T + C \leq 600$

Each of these restrictions means that certain combinations of table-chair output are forbidden. That is, some areas of the table-chair diagram are prohibited. This is shown in Figure 2.

For example, restriction (a) ensures that chair production is less than 450 per week, and the permissible area allowed by it is thus to the left of the vertical line $RS$.

When all restrictions have been depicted on the diagram, it follows that only points which lie within the region $OPQRS$ satisfy all those restrictions simultaneously.

Let us now suppose that the manufacturer wishes to use his resources in such a manner as to make the maximum profit each week.

He knows that he makes a profit (exclusive of fixed costs), of $2 on each table and $1 on each chair, and his fixed commitments amount to $250 weekly. What combination of tables and chairs will give the maximum weekly profit? That is, what point of the figure $OPQRS$ will give a maximum value for the expression

$2T + C - 250$

Now if he were (unwisely) to adopt a policy of manufacturing 100 chairs only per week, he would make a net loss of $150. He could achieve this same result by the production of 50 tables alone per week. In fact, the net weekly loss is $150 for any point along the line $AB$ of Figure 2. The line $CD$ represents points having an equal loss of $50 per week, whilst a profit of $50 is realised anywhere on line $EF$. 
It is apparent, then, that the point representing maximum profit is found by taking a line parallel to AB, CD and EF, and "pushing" it as far to the right as possible. This extreme line passes through the point R, where the weekly production indicated is 50 tables and 450 chairs. The profit thus realised is $300 per week.

In passing we note that although tables appear more profitable per unit, ($2 as against $1), the optimum solution is not obtained by maximising their output. In fact, had he produced quantities given by point Q (100 tables and 300 chairs), his weekly margin would fall to $250.

2.2 Definitions and Points of Interest

The case quoted is an example of linear programming, an extremely useful technique of problem solving.

Linear programming maximises (or minimises) some quantity such as profit (or cost) which is expressed as simple contributions from a number of variables, whilst working within specified constraints.

Its two essential features are thus:

(a) A function to be optimised - the "object function"

(b) Restrictions on modes of operation, usually expressed in the form of equations or inequalities.

Some of its attributes are as follows:

(a) The number of variables (and restrictions) can be as large as necessary to describe the problem. For example, the profit may be expressed as:

\[ P = 2C + 3T + 4W + 9D - 5H \text{ etc.} \]

(b) In the case of a large number of variables, graphical methods fall down, and recourse is made to arithmetic computation, perhaps using an electronic computer. The basic concept is nevertheless unchanged.

(c) The solution to the problem is obtained by selecting a set of the restrictions, and solving them as simultaneous equations. The set of equations chosen will depend upon the value of the co-efficients in the object function. In the example quoted, the relevant equations were the "maximum chairs" restriction and the "labour availability" restriction. If the respective profits of tables and chairs were different, another pair of equations might have to be selected for solution of the operating point.

(d) It is thus seen that at the solution point, not all of the constraints are effective in restricting operation. Furthermore, in many cases some of the variables used to describe the problem will be assigned a value of zero, i.e. they are not chosen in the final answer.

(e) The incremental cost or profit of certain variations can be assessed by changing the numerical limits of the various restrictions.
Only that part of cost or profit should be included which is truly proportional and attributable to the variable in question. If the cost of a certain item has a fixed and a variable component, only the latter should be included.

Hence quantities such as overheads and capital charges should not be allocated to the variables, as they would be incurred irrespectively of the operation of a given plant. Costs of items purchased in definite quantities under contract may be similarly omitted, and their contribution added to fixed costs.

No cost should be placed on any commodity which is both produced and used internally. (This consideration applies to the internal pricing of coke, for example).

Many processes have characteristics which are not truly linear, but approximations to linearity may be made, and answers obtained to problems which are perhaps otherwise insoluble.

### 3. GAS PRODUCTION PROCESSES.

Towns gas which is manufactured by A.G.L. is a blend of components from a number of very different processes, whose products are quite different in physical and economic characteristics.

Those in current use are briefly outlined below:

#### 3.1 Coal Gas

Coal is heated in the absence of air: coal gas is volatilised, leaving coke behind. Heat can be supplied from several media, but usually this comes from burning coke in producers.

![Coal Gas Diagram]

#### 3.2 Carburetted Water Gas

Steam is passed through a bed of hot coke, and this results in the production of 'blue water gas'. Oil or other liquid hydrocarbon may also be injected and is cracked - the product mixture is then called 'carburetted water gas'.

![Carburetted Water Gas Diagram]
3.3 Oil Gas

Oil or other liquid hydrocarbon is preheated and partially cracked to give a gas of calorific value similar to natural gas.

\[
\text{Liquid Hydrocarbon} \rightarrow \text{Oil Gas} \rightarrow \text{Steam} \rightarrow \text{Tar}
\]

3.4 Catalytic Reformers

A liquid hydrocarbon (usually naphtha) is passed through a hot catalyst bed in the presence of steam, and is reformed. With change of catalyst, the same plants can also be used to reform natural gas.

\[
\text{Liquid Hydrocarbon or Natural Gas} \rightarrow \text{Reformed Gas}
\]

3.5 Ballast Gas

A liquid hydrocarbon undergoes partial combustion in air to produce a gas of low calorific value and high density.

\[
\text{Liquid Hydrocarbon} \rightarrow \text{Ballast Gas} \rightarrow \text{Air} \rightarrow \text{Tar}
\]

3.6 Contract Gases

Several gases are purchased from oil refinery based operators. Currently these are blended directly into the towns gas stream without reforming.

\[
\text{Contract Gas 1} \rightarrow \text{Contract Gas 2} \rightarrow \text{Contract Gas 3} \rightarrow \text{Contract Gas 4}
\]
3.7 Boilers

All gasmaking processes make or use steam. Apart from the in-plant waste-heat boilers, some of the byproducts of the various gasmaking processes can be used for steam raising in boilers.

Liquid Fuel
(Oil, Naphtha, Tar)
or
Solid Fuel
(Coal, Coke, Breeze)

Steam

4. STRUCTURING A GAS - PRODUCTION LINEAR PROGRAM.

Since A.G.L. is a public utility, it does not operate so as to maximise profits, which are strictly limited by statute. Rather its objective is to satisfy the demands for its products at minimum cost. Linear programming is a valuable technique here, for the (variable) cost of production can be expressed as a contribution from each type of gas which can potentially be included in the final mix. Thus the objective function of the L.P. is this linear expression of costs, whilst the variables are the quantities of each gas to be produced in each period.

In the optimisation process, numerous constraints must be observed. All of these constraints are expressable as linear relationships amongst the problem variables. The restraints fall into a number of categories:

(a) Market restraints: the quantities of gas, coke and byproducts made available for sale must be equal to the market demands.

(b) Quality constraints: town gas is made as a blend of diverse products having a range of calorific values, density, combustion and other physical properties. The properties of the blend are variable only between closely defined limits. Some of these limits are fixed by legislation, others by the characteristics of appliances installed in customers' premises.

(c) Plant performance and capacity: each of the units described in the previous sections has performance characteristics which may vary with operating conditions such as throughput and characteristics of available raw materials.

(d) Contract restrictions. Many raw materials are bought under fixed contractual arrangements, whence minimum or maximum consumptions might apply. Similarly contracts exist for certain byproducts.

(e) Internal services: sufficient internal services (e.g. steam
and power) must be provided to satisfy the needs of manufacturing and other operating needs.

(f) Standby plant: adequate reserve plant must be available to assure continuity of supply in the event of reasonably likely plant or raw material outages.

If the restrictions described above were written down, the appearance would resemble the matrix array shown in Fig. 3, which would suffice for the description of a single time unit.

Now since gas can be stored, it is not necessary to match supply and demand instant by instant, but fluctuations can be ironed out by reliance on storage. In fact, a planning unit of one week is usually adopted in the industry, with the proviso that short-term fluctuations are carefully monitored.

In planning a year's gas production, one must consider certain facets on an individual weekly basis (e.g. gas quality and output, plant capacity etc.), whilst others must be borne in mind with respect to annual levels (raw material contracts, byproduct output etc.). This combination of considerations means that the matrix tableau describing a year's operations has the following structure.

![Matrix Tableau](image)

The sections $A_1, A_2, A_3 \ldots$ describe constraints on successive weeks' operations.

- **B** is the set of right-hand sides of the restrictions.
- **C** is the cost function which is to be minimised.
- **D** is a set of restrictions which apply on an annual basis.

The time required for solution of a linear programming problem by direct means varies as about the square of the number of variables. To describe fully a year's operations could require about 2000 variables and 1000 constraints, requiring an inordinate amount of computer time for solution. As the pattern of operation is known to be only slowly changing at certain times of the year, a compromise is often made between mathematical exactness and computer time. It has been found adequate to divide a year into 8-12 planning periods without affecting the economic precision of results obtained.
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5. APPLICATIONS OF LINEAR PROGRAMMING.

5.1 Production Scheduling

It might appear from the above description that production planning could easily be undertaken with the use of L.P. However, production managers require planning documents on a fine time scale (i.e. week-by-week schedules), and to undertake to provide such information using a 52 period L.P. would require an excessive amount of computer time.

Based on an extensive and continuing series of L.P. studies, heuristic decision rules have been developed which 'guide' the choice of a production schedule far more quickly, and only a little less flexibly then a full L.P. solution.

The comparative computer times (5 minutes for the heuristic solution v several hours for a full L.P. solution) indicate how the incorporation of some experience can leaven the plodding exactitude of a rigorous mathematical technique.

In any case our experience has been that except in new, unusual or chaotic situations, the use of L.P. will not produce remarkable savings. In matters of routine, the main benefit of computerised production scheduling is in rapid turnaround of results and minimisation of error.

5.2 Incremental Costs of Products

Linear programming has been found to be of considerable use in determining the cost which the Company can afford to pay for its raw materials and the minimum price at which the Company can afford to sell its byproducts. This latter is particularly important where one overseas order can far exceed local annual sales.

The notion of incremental cost becomes important rather than accounting costs which can lead to erroneous decisions in some situations. The incremental cost of gas at a particular level of issue, is the additional cost incurred in producing one more unit of gas over that level. Hence costs which have already been incurred such as capital costs etc. will not be included in the incremental cost if there is spare capacity available in the plants to make the necessary increment. If however the making of the additional increment would require the installation of new plant, then these capital costs would need to be included in the incremental cost, as capital costs are then variable.

Two procedures can be followed in determining incremental costs. Firstly, it is possible in some instances to use information printed out by most L.P. computer packages called "reduced cost". This figure indicates the change in the value of the "cost function" if one additional unit of a particular variable is included. This procedure is not always satisfactory because the costs used in the linear program may not include all relevant costs outside the range for which the L.P. was originally solved.
The better technique is to solve two problems - one with the item whose incremental cost is to be determined at the original level, and a second with the item at some slightly higher level. From a comparison of the costs in the two solutions an accurate incremental cost can be obtained.

5.3 Raw Material Selection

Several situations arise in the selection of raw materials:

(a) A fixed quantity must be consumed at a fixed contract price. Here the L.P. can be used to give advice regarding the optimum schedule of supplies throughout the contract period. If rates of take are governed by maximum or minimum levels, these can be covered by appropriate restrictions in the model.

(b) Quantities are variable and price is known. The model can be solved to choose that quantity of raw material which minimises the overall production cost.

(c) Quantities are variable but price is unknown. This is the situation which classically exists before negotiations for future raw materials are begun. In general terms, if prices are low, the raw material in question will tend to replace competing products as feedstock. With increasing prices, the quantities desired will fall as various applications become uneconomic. The type of information obtained is summarised in the following diagram.

![Diagram showing the relationship between quantity of raw material and total cost of production, with price of raw material as a variable.](image-url)
This type of output is extremely valuable as a basis for management decision making in the negotiation of contracts.

In cases where a number of mutually exclusive raw material options are available, two approaches are possible. Firstly, each option can be substituted in turn into the L.P. array, the problem solved and the various results compared with each other to reveal which of the total operating procedures is the cheapest. Alternatively it is possible to put all alternatives into the one L.P. but by use of "0-1" programming ensure that if one alternative is chosen, then all others are excluded. In practice, at A.G.I. this approach has not been used, partially because the computer packages providing "0-1" programming features have been considered time consuming, but also because the use of several solutions can give the analyst a better "feel" for the problem in hand.

5.4 Byproducts

In the past, when coal gas plant was the only form of gasmaking plants, byproducts such as coke, tar, breeze and so on were produced in direct proportion to the quantity of gas issue. However with the present setup, it is possible to make use of most byproducts on the works either for steam raising or as raw materials in other gasmaking processes. Consequently, the incremental cost of making a byproduct such as coke available for sale needs to be determined so that the selling price of the byproduct truly reflects its value to the Company on the works.

The use of L.P. to determine such incremental costs, overcomes some problems which would arise if accounting costs were used. When a product is produced by one unit of plant and subsequently used in another, the accounting procedure is to credit the area where it is made and to debit the area where it is used at some unit cost. If however one of these areas gets out of phase with the other, and, for example the area producing the product produces far more than the "using" area can absorb, then the accounting procedure does not pick up the unbalance and a vast stock can accumulate with a fictitious book value - fictitious because it has no meaning on the open market. In fact, the use of such erroneous costs tends to create this "out of kilter" situation.

Hence, because the incremental cost of making a byproduct available for sale can be accurately determined by L.P., L.P. can be a valuable tool in determining how big a portion of the potential market for a particular product we can economically supply.

5.5 New Plant Selection

In determining the type and size of new plant to be installed at Mortlake there are many considerations. Firstly it is necessary to ensure that the new plant will provide flexibility in operation. In other words, a breakdown in any one unit of gasmaking plant must not be sufficient to interrupt the supply of gas to any consumer. Hence the quality of the gas produced in the new plant and the capacity of the new unit(s), must be sufficient to meet the expected needs both in quality as well as quantity.
A further consideration in determining new plant is one of capital cost. The question frequently arises as to whether it is more economical to continue with deteriorating plant for say one more year, than to install new plant? Alternatively is it more economical to install a large unit in one year or to install, say, two smaller units over a longer period?

At A.G.L., the problems associated with new plant selection are tackled in two steps.

5.5.1 Type and Size of Plant

To determine how big a plant needs to be installed a series of L.P. studies are carried out for each of the possible new plants under consideration. These studies determine the minimum size of each type of plant which will satisfactorily meet the quality and quantity requirements of our complex.

It is interesting to note here, that the objective function in this L.P. has no relation to money, but aims strictly at minimisation of plant size for given failure conditions.

5.5.2 Economic Study of Potential Plants

Having determined the size of the various possible plants, an economic study is then made of operating costs for a number of years with these new plants assumed available. Again one series of L.P. studies is carried out for each plant being considered. In each study the objective function contains all truly variable costs, but excludes any reference to capital costs, since the size of plant is determined separately as shown in the previous section. Thus each economic study minimises the cost of operation of a particular plant configuration.

In order to give the correct money value to the different years studied, the technique of Discounted Cash Flow is used. This enables greater weight to be applied to costs incurred in the first few years of the plants life than to later years in order to reflect the earning power of the money. Capital costs are included in the year in which they are incurred.

5.4 Solution to General "What Ifs"

From time to time it becomes necessary to answer questions of the "what if" variety. What if price of oil feedstock changes - should we make more use of one plant and less of another? What if natural gas arrives six months earlier than originally planned - should we reform natural gas in all possible plants? What if the operating life of one gasmaking unit is suddenly reduced - how should we operate? What if the rate of inflation suddenly increases - should we invest more heavily in new plant now?

These and many more questions can be answered by solution of our linear programme and use of discounted cash flow. Due to the tremendous flexibility which has been built into the Kortlake system, the change in one item either price or availability can be compensated for by changing other items. But with this flexibility has come increased complexity so that use of a linear programme is almost essential to ensure that no factors which may have an influence on the problem in hand are overlooked.
6. **OBJECTIVE FUNCTION IN L.P.**

As stated above, a linear programme determines a solution to a series of linear constraints such that a linear function, called the objective function, is maximised or minimised.

What costs should be included in an objective function? In general, only truly variable costs should be included. Those items whose costs are made up of a fixed component and a variable component should only have the variable component included. Internal costs (such as described above with respect to accounting procedures) should not be included. Where possible, it is preferable to use 'causative' cost models, i.e. values derived from plant characteristics rather than the blind fitting of regression lines to a variety of accounting data.

7. **CONCLUSION.**

This paper has endeavoured to outline in a fairly non-technical manner the ways in which scientific planning can be of assistance in aiding the process of management decision making.

Linear programming has been used at A.G.L. to plan the choice, installation and use of the Company's production facilities in a period of great change. The results of this planning can be seen in the almost complete transition from coal to refinery products, from carbonisation to catalytic reforming. As well as being less labour-intensive, the plant is now flexible and adaptable to many forms of exogenous change, including feedstock quality and price, the incidence of natural gas and growth rates of markets. In arriving at this (reasonably) happy situation, Management has been able to see on paper the implications of many hundreds of alternative schemes, and make their decisions on a far sounder basis than would otherwise have been possible.
AN IRON ORE ALLOCATION MODEL

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1. INTRODUCTION

As is well known, the Broken Hill Proprietary Company Limited is an organisation within which there are three major steelworks, viz., at Newcastle, Port Kembla and Whyalla, and a plant at Kwinana producing pig iron. By the late 1970's a steelworks will also be operational at Westernport. The three most important raw materials required by the works for production of iron are iron ore, coal, and limestone. As will be explained later a particular allocation of iron ore from the quarries to the works has a bearing on the total annual output of hot metal (i.e. molten iron produced from the blast furnace). It also has a bearing on the cost per ton of hot metal produced.

The formulation and control of the Company's future planning is in the hands of the Production & Planning Departments at the Company's Head Office in Melbourne. One of the requirements of these departments is the production each year of a future planning program covering a ten year period, year by year, after the budget year. In the future planning program the Company forecasts the amount of hot metal that it considers necessary to make each year to meet the forecast annual steel demand. Associated with the hot metal make is the allocation of iron ore necessary to meet the hot metal make.

This iron ore allocation problem is one of major dimensions, and the determination of an optimal solution was undertaken by the Systems Engineering Department at Australian Iron & Steel Pty. Ltd., Port Kembla.

This paper describes the formulation of the problem and the successful solution of one of its stages. It focuses attention on the use of the linear programming (LP) technique in solving complex allocation problems. It also focuses attention on the necessity for developing auxiliary routines before such a model can be successfully used by management as well as by the developers.
Production of pig iron or hot metal is a thermochemical process in which iron ores of various types and processed iron bearing materials such as sintered ore (sinter) and ore pellets are used. The iron oxides contained in these materials are reduced to iron in the blast furnace. Subsequently, the hot metal is used to produce steel in either the Basic Oxygen Steel (B.O.S.) or the Open Hearth furnace.

Currently, there are four iron producing works within the Company with a total of 11 blast furnaces in operation. There are four blast furnaces at Newcastle, four at Port Kembla (a fifth is due for commissioning later in the year), two at Whyalla and one at Kwinana. There are also plans for increasing the number of furnaces at each of the works in the future. A fifth ironmaking works is also planned for construction at Westernport Bay.

[Map showing various locations and labels: Yampi Sound - iron ore quarries, Mt. Newman - iron ore quarries, Middleback Ranges - iron ore quarries, Whyalla - steelworks, Koolyanobbing - iron ore quarries, Kwinana - blast furnace, Newcastle - steelworks, Port Kembla - steelworks, Westernport - future steelworks development, Melbourne - B.H.P. Head Office]
Iron ore currently comes from five sources, viz., Whyalla, Koolyanobbing, Mt. Newman, Koolan Island and Cockatoo Island. A number of "new sources" are also being considered for future development.

The operation of a blast furnace is constrained by material handling and charging equipment. Capacity and reduction rate vary from one furnace to the next. The suitability of a particular ore in a particular furnace depends not only on its cost but also on its chemical and physical properties and how easily it can be mixed with the other ores used to give a satisfactory ore blend.

The hot metal production of a furnace depends on the chemistry of the ore (i.e. % Fe in the ore) and the size and strength of the ore. Very fine ore ("fines") is detrimental to production and steps are taken to screen all the iron bearing materials to some particular extent at each of the works. The fines are then used in making sinter. Sinter is the end product of a process which converts, at a high temperature, ore fines and other iron bearing materials of small particle sizes, together with finely divided coke, into porous coherent lumps which are well suited for use in the blast furnace. Excess fines which are unable to be consumed by the sinter plant at the particular works have to be stock piled at that works.

Whyalla blast furnaces are not considered in this model as they operate on 100% Whyalla ore and therefore cannot enter into any optimisation. Whyalla works also produces partially reduced ore in the form of pellets some of which are available to other works.
3. OBJECTIVES

The initial objective of the project was to develop a model of the Company's ore mining and ore reduction processes in such a way that it would be possible to maximise iron production, either Company wide or at any given works, subject to meeting minimum production levels at the rest of the works. This results in an optimal allocation of iron ore to the ironmaking centres subject to the following broad constraints:

i) Ore quarry operating levels, including availability of pellets.
ii) Restrictions on the availability of any particular ore type to a particular works.
iii) Sinter plant operating levels at each works.
iv) Lump ore requirements of a particular ore type by the steelmaking furnace.
v) Minimum hot metal requirements for each works.
vi) Availability of coke at each works.

It is this stage of the project which has been so far developed and successfully implemented, even though considerable work still has to be done in generalising aspects of the data input and generation of reports required by management.

Future development of the model proper will be to change the objective such that the allocation of iron ore will make it possible to produce the required amount of hot metal at each of the works at least cost to the Company. Also, the model will be expanded to assist in facilities planning to allow determination of the cost and consequences of locating new mines or new agglomerating plants at any given location. The model will thus also enable the assessing of economic consequences of exporting iron ores on the Company's hot metal costs.
4. DEVELOPMENT OF THE MODEL

4.1 Choice of Technique

Whenever a process involves the blending of a variety of materials within specification constraints, the application of LP techniques enables the producer to determine rapidly the optimum blend depending on some objective function. The usefulness of LP increases as the number of materials and the complexity of the industrial process increases.

The problem of allocating iron ore from quarries to blast furnace involves precisely the sort of complex planning and control problems which LP is designed to solve.

Contrary to popular belief something more than a little mathematical knowledge is required to formulate an LP model designed to depict a complex problem, and most problems encountered in industry, particularly in the steel industry, are complex. For this problem it was also necessary to be something more than familiar with the operation of the computer and the structure and capability of the LP computer packages.

Linear programming requires the expression of all the elements in the process in the form of simple linear equations. It became obvious early in the development of the model that a number of equations, (viz., average sinter rate and average smelt rate equations) are non-linear. There are three possible ways out of the predicament:

1) To embark into highly technical research to develop a technique capable of solving the problem exactly.

2) To restructure the model so that it will be capable of being resolved by the method of separable programming.

3) To "bend" the model slightly so that it can still be solved by LP so long as the answers were within acceptable error bounds.
For practical reasons the choice lay between methods 2 and 3 with method 3 being eventually selected. A detailed discussion of this can be found in section 5.

4.2 Choice of Computer and LP Package Used by the Model

The model both in its current state and in the future, must be capable of being run on a computer at Melbourne, Port Kembla and Newcastle and eventually at Whyalla and Kwinana.

The Company currently has two CDC 3300 computers at each of the works at Port Kembla and Newcastle. As well, the Company has a terminal to the CDC 6600 computer situated in Sydney, at Port Kembla and at Newcastle and will shortly have one at Head Office in Melbourne.

OPAL is the only LP package available on the CDC 3300 machines. The model was initially run under OPAL and it was found that the elapsed time to produce a one year allocation would take approximately 1½ hours. Apart from practically inhibiting, multi-programming of the computer (being compute bound), this prevented proper development of the project through lack of availability of computer time. The model was then converted to run under the OPTIMA LP package on the CDC 6600 computer. By comparison a one year allocation takes 1½ minutes under OPTIMA.

4.3 System Specification

The overall system commences with an edit routine which checks all the input data for the LP and creates a file containing this information. A matrix generating program then accesses this information, creates the appropriate equations in standard OPTIMA format and writes the associated OPTIMA control program. Control then passes to the OPTIMA coding which solves the LP problem with the aid of a starting basis and several pre-compiled programs. Several reports are also generated from each solution of the LP. Finally, all unwanted files and output is released and the reports and other standard output are stored on files for two hours, to allow post-analysis if required.
The edit routine is supplied with data via pre-formatted cards. All input data is sorted initially using a card-code as a key and placed on a Scratch File, INFO-FILE. Each field is checked for legality according to its specification. For example, all numeric fields are checked to be numeric and to be within any applicable bounds as well as in accordance with any cross referenced information. Any ore arriving at an ironmaking centre is checked to see that it is an allowable destination for that ore and to see that it has been in fact sent from that particular quarry. All place names are checked as a legal destination or source of ore, as the case may be.

If the information is found correct it is transferred to a file (MAGEN) in a form compatible with the matrix generator. Simultaneously, a report on the information is printed, enunciating the data.

If, however, the data does not pass the edit, the appropriate field is underlined and the card image printed with an explanation of the suspected error. In all cases of suspected errors a value is assumed by the program and this information is written onto the MAGEN-FILE and also included in the data summary, flagged by **ASSUMED**.

The matrix generator performs several unit operations to set up the entire LP System. Firstly, it generates the matrix in standard OPTIMA format. This is done simply by writing all the logical variable and structural variable name cards, as card images, onto the data file, ALLOC1. Working within this matrix the program now accesses the edited information on MAGEN and produces all appropriate indirect, bound, range and right hand side cards which are then used to produce the relevant equations. Indirect values are initialised and subsequently changed, if required, for each new right-hand-side. The application control language (ACL) program is then generated subordinate to each right-hand-side. This may require the purging of the old Workfile, setting up a new Workfile with its associated range and bound sets, setting the appropriate right-hand-side, objective junction and scaling function, mapping in a starting basis and the recalling of PRIMAL.
In accordance with the information supplied, the matrix generator produces the relevant equations depending on whether:

1) ore is screened at the quarry or shipped as run-of-mine (ROM).
2) a bedding plant exists at that centre.
3) an excess of "fines" is allowed at that centre.

All equations are set up as described later in the following sections.

Having completed the above program, control passes to the OPTIMA ACL program (written by the matrix generator). This program sets up all the indirect values, both for the LP solution and report generators. It then maps in a basis and solves the LP for each right-hand-side. After the initial solution of the LP control drops to an 'iterating' routine which adjusts all first-order approximations for non-linear constraints by recalculating the indirect coefficients in the matrix. Control then returns to the ACL program where PRIMAL resolves the LP. This procedure is repeated several times for each right-hand-side, until sufficient accuracy has been attained.

At this point several reports are produced using the current solution. Included in these reports are:

1) A report on the total ore of each type used in the solution.
2) The allocation (fines and lumps) for each ironmaking centre and the resulting iron production, sinter-make and any excess fines produced.
3) The shipment report (only printed at the end of the run) is updated from the current allocation.
4) The total reserve report is also updated. All these reports are published onto a file TEMP which is printed at the completion of the run. However, the final LP solution in standard form is written onto a file TEMP 1 (for each right-hand-side) and exists for two hours.
after the run to allow a detailed post-analysis of the LP solution if required. A complete output from the LP run may also be obtained for up to two hours after the run from a file TEMP 2. This information is only obtained if required for debugging purposes.

If an infeasible solution results from a particular solution, at any time, a special report is produced which enables the user to correct his solution on the succeeding run. No further processing of the solution for that particular right-hand-side is obtained and control immediately passes to the next right-hand-side of the problem (if any).

4.4 Constraint Specifications

a) Quarry Constraints

Ore may be shipped from a quarry in either of two forms:

i) The ore is shipped as run-of-mine (ROM), or,

ii) Screening of the ore at the quarry results in the ore being shipped as either lumps or fines.

Rescreening of the lump ore at the ironmaking centres produces a further fine ore proportion. The equations for the quarries are as follows:

i) Distribution Equations

Obviously, the total ore distributed must fall within the operation levels of the quarry and hence the equation is:

\[ \text{LOWER LIMIT OF OPERATION} \leq \sum_{i=1}^{n} \left( F_i^j + L_i^j \right) \leq \text{UPPER LIMIT OF OPERATION} \]

where \( F_i^j \) = tonnage of fines of type \( i \) sent to location \( j \).

\[ L_i^j = \text{tonnage of lump of type} \ i \ \text{sent to location} \ j. \]

\( n = \text{no. of locations served by that particular quarry} \).
ii) Fines/Lumps Ratio

These equations reflect the mode of shipment of the ore type (i.e. ROM or Screened). If the ore is sent as ROM the equation will be:

\[ X_i^j \times P_i^j - (1 - X_i^j) \times L_i^j = 0 \]

However, if the screening takes place at the quarry this equation becomes:

\[ \sum_{i=1}^{n} (X_i^j \times P_i^j - (1 - X_i^j) \times L_i^j) = 0 \]

where \( X_i^j \) = lump proportion of ore \( i \) when screened at location \( j \).

b) Balance Equations

These equations simply sum the tonnages of "fines" and lump ore at each ironmaking centre.

i) Fines Balance

\[ T_i^j = \sum_{i=1}^{n} (P_i^j + A_i^j \times L_i^j) + M_i^j \]

where \( T_i^j \) = total tons of fines allocated to centre \( j \).

\( A_i^j \) = proportion of fines re-screened from the lump ore \( i \) at centre \( j \).

\( M_i^j \) = tonnage of iron bearing additives in the sinter burden at centre \( j \). These are essentially recirculative in nature.
ii) **Lump Balance**

\[ R^i_j = \sum_{i=1}^{n} (1 - A^i_j) \times L^i_j \]

where \( R^i_j \) = total tonnage of roughs (+V) at centre j.

iii) **Excess Fines Balance**

This equation simply equates the total tons of fines allocated to the sum of the sinterable fines and the excess fines for each centre.

\[ T^i_j = SF^i_j + XF^i_j \]

where \( SF^i_j \) = sinterable fines at centre j.
\( XF^i_j \) = excess fines at centre j.

c) **Sinter Equations**

As mentioned previously, "fine" ore when charged directly into a blast furnace is detrimental to production. In practice any "fines" unable to be consumed by the sinter plant would be stock piled. In the model they are treated as an ore type with a heavy penalty on production. Because the objective of the model is to maximise iron production, it automatically attempts to reduce the amount of "fines" to zero.

The sinterability of fine ore is characterised by its sinter rate which is determined experimentally. It differs markedly for each ore type and can be different at different sinter plants for the same ore type.

The sinter equations have the following form:

i) **Average Sinter Rate**

\[ \text{Average Sinter Rate} = \sum_{i=1}^{n} (SR^i_j \times \% P^i_j) \]  

ii) **Sinter Production**

\[ \text{Sinter Production} = \text{Av.SR} \times \text{Hearth Area} \times \text{Availability} \times \text{Time} \]  

iii) **Sinterable Fines**

\[ \text{Sinterable Fines} = \text{Sinter} \times \text{Yield} \]
Where \( F^j_i \) = tonnage of fine ore of type \( i \) at centre \( j \), including rescreened lump and mill scale, flue dust, etc.

\( SR^j_i \) = sinter rate of ore fines of type \( i \) at centre \( j \).

From the above equations it is possible to determine the sinter production and the total consumable fine ore (i.e. Sinterable Fines).

Obviously, the average sinter rate equation is non-linear. To overcome this, as in all other cases of non-linearity in the model, a first-order approximation to the equation at a 'known' point is used. Later, the matrix is updated on the basis of the solution and the optimising routine PRIMAL recalled.

The first-order approximation equations are defined as follows:-

\[
X_o = \sum_{i=1}^{n} (SR^j_i \cdot F^j_i) - \Delta x
\]

\[
Y_o = \sum_{i=1}^{n} F^j_i - \Delta y
\]

where \( X_o \) is the initial estimate and \( \Delta x \) the probable error in the quantity \( (SR^j_i \cdot F^j_i) \) and \( Y_o \) is the initial estimate and \( \Delta y \) the probable error in \( F^j_i \).

Substituting (5) and (4) into equations (1) and (2) we obtain:

\[
\text{Sinter} = k \frac{X_o}{Y_o} + \frac{k \Delta x}{Y_o} - k \frac{X_o \Delta y}{Y_o^2}
\]

where \( k \) is a constant.
The sinter production is then equated to total consumable fines.

After, an optimum solution is obtained, the estimates X₀ and Y₀ are updated, and the PRIMAL routine recalled to determine the new optimum solution. This can be repeated until sufficient accuracy is obtained.

d) Lump Distribution Equations

These equations distribute the lump proportion of the ore type (including pellets and sinter) to the individual blast furnaces. The lump proportion always allows for rescreening.

\[ R_{ij} = \sum_{f=1}^{k} (LM_{if}) \]

Where \( R_{ij} \) = total lump ore of type i at centre j.

\( LM_{if} \) = tonnage of lump ore of type i to furnace f.

\( k \) = no. of blast furnaces at centre j.

e) Iron Production Equations

The iron bearing components of the burden charged into a blast furnace can consist of lump ore of various types, sinter, pellets, and at least theoretically, "excess fines". The contribution to the productivity of a blast furnace by each of the abovementioned components is depicted by assigning a smelt rate to each of the components. These smelt rates were determined experimentally by conducting a series of trials where a blast furnace operated on specified burdens.

Smelt rates for "new source" ores which are only being planned for mining can be determined by making an educated guess taking into account the ore's chemistry and physical properties.
Having thus graded the ores on performance in a blast furnace, it only requires the knowledge of the average hot metal production rate of each blast furnace working on any given burden to be able to determine the hot metal make for any given iron ore allocation.

The iron make equations can be of two types, depending on whether the ironmaking centre has an ore bedding and blending plant or not.

1) **Without a Ore Bedding Plant**

The iron make equations are similar in nature to the sinter equations except that an average smelt rate (SMR) of the burden is calculated, rather than an average sinter rate.

The first-order approximation equations are identical in nature to the sinter equations.

The following are the equations used for each furnace:

\[
\text{Av. Smelt Rate} = \frac{1}{n} \sum_{i=1}^{n} (\text{SMR}_i \times \% \text{LM}_i)
\]

**Iron Make** = \( k \times \text{Av. SMR} \)

Where \( \text{SMR}_i \) = smelt rate of ore type \( i \)

\( \text{LM}_i \) = tonnage of lump ore of type \( i \) allocated to centre \( j \)

\( k \) = conversion factor, for the particular blast furnace, which depicts the geometry, operation and condition of the furnace.
ii) With a Bedding Plant

When a bedding plant is in operation the resulting bedded lump ore will have an average smelt rate, and this lump ore as well as the pellets and sinter, may be fed to the furnaces to produce a further average smelt rate which will govern the production of each furnace. The average smelt rate for each furnace, $f$, is given by:

$$\text{Av. SMR}_f = \frac{\text{Sinter} \times \text{SMR}_s + \text{Pellets} \times \text{SMR}_p + \text{Blend} \times (\text{Av. SMR}_b)}{\text{Total lump to furnace } f}$$

(7)

The iron production for each furnace is then given by:

$$\text{Iron Production} = \text{Av. SMR}_f \times \frac{1}{k}$$

(8)

Where $\text{SMR}_s$ = smelt rate of sinter

$\text{SMR}_p$ = smelt rate of pellets

$\text{SMR}_b$ = smelt rate of blend, and,

$k$ = is defined as before.

Again, by taking a first-order approximation to equation (7) and substituting into equation (8) yields the equation:

$$L \times P + \left(P + S - K \times F \times F_{Fe} \right) \times L + L \times S + A \times S \times B_f + B \times A \times S - K \times L \times F \times F_{Fe} = K(-2E \times L \times F_{Fe}) + P \times L + S \times L \times B \times A$$

(9)

Where $L$ = Total tonnage of lump ore in bedding plant.

$P$ = Tons of pellets * its smelt rate to furnace $f$. 
\[ S = \text{Tons of sinter} \times \text{its smelt rate in feed to furnace } f. \]

\[ AS = \text{Tons of blended lump} \times \text{its smelt rate for feed to furnace } f. \]

\[ F = \text{Total lump feed to furnace } f. \]

\[ K = \text{Constant} \]

Suffix \( a \) denotes an expected value for these quantities.

**f) Iron Balance Equations**

The iron-make equations predict how fast the furnace can produce iron from a given blend of ore at their current (or expected) mode of operation and condition. However, a further constraint has to be imposed to ensure that enough feed is available to satisfy the stoichiometry of the ore. To this end a conversion factor \( Z \) is used to convert iron to the requested amount of ore. The ore must be allocated ore and does not include sinter plant additions and allows for sinter plant yields.

The conversion factor \( Z \) is different at each of the works. It is determined empirically and takes into account losses of ore due to spillages of various types, wind, etc.

The iron balance equation, for each of the works is of the form:

\[
\sum_{i=1}^{n} LM_i^j = Z \times Fe_i^j
\]

Also, lower bounds are placed on the hot metal production at each centre.

**g) Coke Equations**

The coke requirements are equated to the iron-make by the average coke-rate determined empirically at each ironmaking centre. This can be used as a constraint or as an indication for reporting purposes.

\[ \text{Coke}_j^j = \text{Total Fe}_j^j \times \text{Coke Rate}_j^j \]

The coke\( _j^j \) may or may not be constraining at the ironmaking centre \( j \).
h) Phosphorus

These constraints keep the phosphorus level in the iron below a specified level assuming no losses in slag, flue dust or in the sinter plant. The two constraining equations used are:

\[ \text{Phos}^j = k^j \sum_{i=1}^{n} (PL^j_i + PF^j_i \times Y) + \text{Coke Phos}^j \]

\[ p^j = (\text{phos}^j / \text{total iron}^j) \times 100 \leq \text{specified level.} \]

Where

- \( \text{Phos}^j \) = total phos. in hot metal.
- \( k^j \) = yield at centre \( j \) of phos. from furnace ore burden to hot metal.
- \( PL^j_i \) = phos. is lump ore \( i \) at \( j \).
- \( PF^j_i \) = phos. in fines ore \( i \) at \( j \).
- \( Y \) = phos. yield from sinter plant.
- \( \text{Total Iron}^j \) = total iron production at centre \( j \).
- \( \text{Coke Phos}^j \) = total phos. in coke at centre \( j \).
- \( p^j \) = percentage phos. in hot metal at centre \( j \).

i) Objective Function

The objective function has the form:

\[ \sum_{i=1}^{P} (a_i \times \text{HM}_i) = \text{maximum} \]

Where

- \( P \) = no. of ironmaking centres.
- \( a_i \) = constant.
- \( \text{HM}_i \) = hot metal produced at centre \( i \).

If the objective is to maximise total hot metal make in the Company, all \( a_i \) will be unity. If it is desired to favour one or more ironmaking centres at the expense of others then the \( a_i \) will, accordingly, be different.
5. TREATMENT OF NON-LINEAR CONSTRAINTS

The non-linear constraints encountered in this model could have been handled by a powerful general method known as "Separable Programming". This method assumes that all the non-linear constraints can be separated out into sums and differences of non-linear functions of single variables.

As a method, Separable Programming was rejected on two counts. Firstly, if ever a decision is made to convert and run the model on the Company's CDC 3300 computers under the LP package OPAL, it would not be possible since OPAL does not possess this feature. Secondly, if the method was adopted, as is possible, using the LP package OPTIMA, the size of the problem matrix would be more than doubled with a subsequent increase in computer time required and corresponding increase in computer costs.

The method finally, and successfully, adopted to handle the non-linear constraints was to substitute a first-order approximation at a point to the curve, for each of the non-linear constraints, and use the gradient at that point as the constraint for the first solution to the problem. After an optimal solution has been found, a routine is entered which takes the solution values of the variables in the approximating constraints (which will differ from the initial guessed values) and the actual points on the curves are recalculated using the exact constraints. A new gradient is calculated for the curve at this "more exact" point and the LP routine is re-entered to determine a new optimum solution. This routine can be repeated until the desired accuracy is achieved.

From actual results it would seem that the errors in the approximating constraints converge to zero slowly after the first few iterations, if in fact convergence to zero exists at all. However, in all computer runs so far, it was found that after the first solution and three subsequent iterations, the magnitude of the errors was less than 0.5%, which is more than acceptable for this application.
6. COST-EFFECTIVENESS OF THE MODEL

The cost to date in salaries to staff engaged in developing the model is equivalent to two man years.

The cost of program development, i.e. computer costs, is a significant proportion of the total cost. To date 10,000 system-seconds time has been spent on the CDC 6600 computer. The average computer run to produce a one year allocation takes 100 system seconds - the current size of the problem matrix is 127 constraints in 185 variables. The average computer run to produce a ten year allocation takes 400 system seconds.

The savings, or more appropriately, the value obtained from developing the model to its existing status can accrue from the following areas:

- Additional marginal production
- Improved loading of existing facilities - sinter plants and blast furnaces
- Improved method of assessing the need, the size, and the timing of capital expenditure on planned facilities.

It is impractical to be quantitative in placing a dollar value on the abovementioned benefits. However, if it is conceded that the current model can save, say, one cent per ton of iron produced, then this is an annual saving of the order of $75,000, and this is being conservative to say the least.

The author is not unduly concerned about the inability to be quantitative in stating the cost-effectiveness of the model.

It is more important to note that management has assessed the usefulness and the need for such a model, and expressed willingness to implement it, in the planning, development and allocation of the Company's iron ore resources.
7. ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the Broken Hill Proprietary Company Limited for permission to publish this paper and to Mr. H. Wiltshire, formerly of Australian Iron & Steel Pty. Ltd., for his assistance in the development of this work.
CARD INPUT

SORT DATA ON CARD CODE (SCRATCH1)

SORTED INFO-FILE (SCRATCH2)

EDIT PROG

REPORT ON EDIT ERRORS (PRINT-FILE)

SUMMARY AND ASSUMPTIONS WRITE-FILE (SCRATCH3)

PRINTOUT OF WRITE-FILE

DATA FILE MAGEN INPUT TO LP

MATRIX GENERATOR

PROBLEM FILE IN STD OPTIMA FORM

OPTIMA A.C.L. PROG

COMPILED REPORTS & BASIS

TOTAL OPTIMA OUTPUT (TEMP2)

REPORTS ON SOLUTIONS (FROM FILE TEMP)

FILE CONTAINING STD RECORD OUTPUT (TEMP)

TOTAL SYSTEM FLOW
INTRODUCTION:
Management is concerned with the exploitation of business opportunities. In its simplest terms, the problem is one of increasing beneficial outputs (profits, goodwill, etc), for a given level of input (Figure I) and, where possible, to understand the relationships between them so that the decision making process in company operations may be continuously improved.

FIGURE I
Projects, as independent units of work, which require resources and yield benefits, are the means for studying this relationship and for implementing any decisions based on it. Project formulation is consequently a vital planning activity bridging the gap between concept validation/opportunity analysis and execution of the
resulting project. (See Figure II). It includes such activities as:

* Determination of acceptable project versions
* Identification of possible project outcomes
* Examination of the implementation requirements
* Selection of the "best" version of the project.

**FIGURE II**

The financial success of projects appears to depend on the way in which cost-benefit analysis has been applied in determining their form and implementation requirements. Thus, project failures may well be due to inadequate planning rather than poor judgement in estimating costs and benefits. The method of project control could, for example, seriously influence the financial outcome of the project by determining how quickly adverse situations (eg: project hold-ups) were brought to management attention!

The objective of this paper is to identify from cost-benefit considerations weaknesses in current approaches to project formulation and to recommend improved management aids in this field.
COSTS AND BENEFITS:

At the time of project formulation there are three classes of cost and three classes of benefit that need to be considered:

![Diagram showing identifiable costs and identifiable benefits connected to project formulation, with unidentified costs and unidentified benefits.

FIGURE III

Examples of each class of cost and benefit may be found in the first stage (1) of an Instrument Shop Study carried out for Unilever (see Appendix A) in the U.K.

IDENTIFIED COSTS:

(i) Cost of the survey

(ii) Cost of data analysis

(iii) Cost of implementing and operating a Job Control and Processing System.

UNIDENTIFIED COSTS:

(i) Lost opportunities if instrument jobs were not submitted.

(ii) Competition for machines between jobs (Phase II included plans for machine scheduling).
INTANGIBLE COSTS:
May arise if more scientist involvement was required initially to minimize labour requirements.

IDENTIFIED BENEFITS:
(i) Savings in management time
(ii) Improved service (ie: user control of priority!)
(iii) Greater throughput for the same labour force.

UNIDENTIFIED BENEFITS:
(i) Administrative savings
(ii) Basis for machine scheduling

INTANGIBLE BENEFITS:
(i) Improved morale
(ii) Identification of future data requirements.

The approach adopted in evaluating projects is characterised by the way in which these classes of cost and benefit are used:

eg: I. Cost-Benefit Analysis:
(i) Unidentified costs/benefits treated as possible constraints.
(ii) Attempt is usually made to value "intangible" on some basis.

II. Project-Evaluation with Mathematical Models:
(i) Unidentified benefits/costs treated as range of uncertainty. (c.f. use of risk analysis!)
"Intangibles" largely ignored, except as constraints.

Scope for improvement can be seen in the fact that neither method gives management a realistic interpretation of all the projects' characteristics. What is generally necessary is a more exhaustive study of the range of project outcomes and the key factors determining their likelihood of occurrence, in conjunction with the use of mathematical models.

PROJECT OUTCOMES:
The object of undertaking a project is to achieve a positive financial result, although the balance sheet may require a value to be attributed to such imponderables as:

(i) New skills acquired
(ii) Patents obtained
(iii) Public and Government goodwill (e.g.: pollution problem has been solved!)

before any project would be judged a success or failure. Project formulation, then, should reduce any uncertainty associated with meeting this objective.

Where does the greatest uncertainty lie? - Unidentified costs and benefits, I suggest!

To a first approximation, then, the objectives of project formulation are:
(i) Minimization of unidentified costs
(ii) Maximization of unidentified benefits.

ORIGINS OF UNIDENTIFIED COSTS:

Ideally, this subject would merit a paper by itself, but the following factors are believed to be some of the more important:

(i) TIME DELAYS:

Consider a typical project life cycle A (figure IV).

A delay in completing the project will have three effects:

a) Defers the time at which benefits start to appear. i.e.: A liquidity problem could develop.

b) Reduces the likelihood that the scale of anticipated benefits is realized due to competitive action.

c) Reduces the present worth of benefits.

The value of the project can consequently suffer considerable reduction and even lead to a loss situation if cost escalation occurs. (e.g.: Rolls Royce Engine Division).

![Diagram](image-url)
(ii) ERRORS IN ESTIMATING:

The effect naturally depends on the seriousness of the errors and the profit margin on which the Company is working to. In recent years poor anticipation of the market interest rate on short term money has caused considerable problems with a tight liquidity position.

(iii) TECHNICAL DIFFICULTY:

Technical difficulty, while not necessarily delaying the project as a whole, may increase costs in many ways:

eg: a) increased staff or consultations required
b) expensive analytical instruments are necessary due to analytical problems.

(iv) GOVERNMENT ACTION:

More stringent requirements in respect of quality, performance etc, may be imposed during the life of the project (eg: car exhaust omissions), or former allowances may be withdrawn (eg: investment grants).

(v) INADEQUATE CONTROL MECHANISM:

Inadequate control in project implementation may take several forms:

a) Poor strategy (eg: lack of check points!)
b) Duplication of effort between departments
c) "Warning signals" identifying problem situations not being recognised due to poor project progressing method(s).
Heavy additional costs are generally incurred if project control is inadequate.

EXPLOITATION OF UNIDENTIFIED BENEFITS

Possible methods for achieving unidentified benefits are:-

(i) Develop product earlier.

(ii) Sell or exploit accidental discoveries (spin-off!)

(iii) Create new ways of influencing the market. Thus, the Hills Hoist clothes dryer was developed as a compact, collapsible, sightly clothes line. However, in Australia and the U.K. it is being marketed as a combined clothes line and sunshade. It immediately appeals to a wider market!

(iv) Lobby for specific Government support, particularly for fledgling industries.

(v) Research new Project Management techniques.

With so many sources of hidden costs and benefits, it is wise to know for which situations the viability of the project would be critically dependent on such factors. Four situations occur quite frequently in practice, but there will surely be more:

a) SCREENING PROJECTS

Screening of compounds or new product formulations for a specified activity (e.g. pharmacological action) often involves difficulty in planning for the most effective project organization and resource deployment. A network approach to this problem (see figure V) has been evolved at Unilever(2) using three parameters for each activity.
NETWORK ANALYSIS OF SCREENING PROJECTS

BEST CONFIGURATION?

FIGURE V
(i) Minimum time before a result is known
(ii) Probability of reaching or exceeding the desired level of activity.
(iii) Thruput for a given level of manpower.

b) COMPETITION FOR RESOURCES

Queuing, due to competition for resources, can be a major problem. The solution may require a rigid set of priorities from management, a full simulation exercise or the development of a 'Queue Ordering Formula' for dynamic control, (e.g. the Instrument Shop problem).

c) TECHNICAL CONSTRAINTS

Technical objectives defined too narrowly can be self defeating for two reasons:

(i) The objectives may be harder to achieve
(ii) Side-benefits may be lost. e.g. a plastic developed for house insulation may be a suitable packaging material!

On the other hand, the technical objectives may be too broad. It is often the case that a market need is known to exist (e.g. from market research or industrial surveys), but the 'best' project to satisfy that need is not immediately clear. This is particularly true for products for which consumer beliefs are related only with difficulty to laboratory test methods.
d) OFFICIAL PERMISSION

Where radical advances are being made in technology (e.g. the Supersonic transport) official permission of some nature may be a critical determinant of commercial success. Costs may easily get out of hand in satisfying newly imposed standards. In general, then, project determination should be concerned with the range of possible project outcomes rather than the relatively easily quantified benefits and costs associated with the one expected result. In practice, it is helpful to include several versions of the project for consideration of possible project outcomes and to treat the project evaluation step as the selection of the 'best' version.

PROJECT EVALUATION

Cost / Benefit analysis is based on such questions as:

a) Which costs and which benefits are to be included?
b) How are they to be valued?
c) At what interest rate are they to be discounted?
d) What are the relevant constraints?

As currently applied it appears to suffer from certain limitations:

1. Only identifiable benefits and costs, but including secondary items, are actually used in the analysis.
2. The cost implications of project control are not considered.
3. Interaction between different classes of benefit are ignored in the Discounted Cash Flow (DCF) calculation.

4. Risk analysis is difficult to apply directly.

5. Mathematical consequences of the DCF formula are not considered in full.

Refinement of the DCF calculation, mathematical modelling and other techniques should consequently be explored more frequently to overcome such weaknesses.

Discounted Cash Flow Calculation:
Some problems in using the DCF technique for projects with unusual cash flow profiles have recently been solved by Joe Kruithof (4). The mathematical treatment provides solutions to those cases where a 'second phase' of investment follows the receipt of some benefits, but the discount rate to be applied to this investment is less than the discounted rate of return of the project.

Mathematical Modelling:
Significant benefits for project evaluation stem from the use of mathematical models. Since the early sixties, growth in this area has been spectacular:

(i) Benefit Estimation
For many projects a sigmoidal growth of benefits can be assumed followed by obsolescence. (see figure VI)
The problem, then, is to determine the parameters for this curve for a particular project. Essentially the method of choice is likely to be:

a) Establish a procedure for determining the theoretical maximum benefits.

b) Relate the likely achievable benefits to this maximum on a yearly basis.

From a study of the mechanisms of the transfer of technology, BISRA evolved a model \(^{(5)}\) in which the rate of spread of a technology through an industry would follow a logistic growth curve.

\[
\frac{dp}{dT} = k \cdot p(1 - p)
\]
Thus, the proportion of firms innovating over a small period of time (dT) will be proportional to the frac­tion of firms 'at risk' and the pressure to innovate represented by the fraction which have innovated (P). The proportion of firms which will have innovated after time T can then be described by the logistic:

\[ P(T) = (1 + ae^{-bt}) - 1 \]

Thus, the achievable benefits of a new technology can be calculated using the BISRA model. Actual benefits realized will depend on such factors as:

* Correct identification of project outcomes
* Market Coverage
* Competitive action (product launches etc.)
* Quality of service.

The modelling approach to benefit estimation is likely to prove increasingly popular:

a) Contribution from any source can be modelled.

b) Current market information can be used to estimate the required parameters.

c) Provides directly observable Project Control criteria.

ii) PROJECT ANALYSIS

Several outcomes (project versions) for the project may have been identified. The problem, then, is to represent and analyse a series of multichoice investment decisions to be made over time. The decision tree approach was deve­loped (6) for this purpose. Consider the use of a Decision Tree to analyse investment alternatives for a New Product introduction (7) (see figure VII). The version that maximizes the expected NPV of the entire decision tree is deemed to be the optimal policy.
USE OF DECISION TREES TO ANALYZE INVESTMENT ALTERNATIVES FOR A NEW PRODUCT INTRODUCTION.

FIGURE VII

NPV $M

1  
4.5
0.5
2.5
2
7.5
1
-4

LIMITED DEMAND

P = 0.3

LARGE DEMAND NATIONALLY

P = 0.71

LIMITED NATIONAL DEMAND

P = 0.2q

DISTRIBUTE NATIONALLY

INTRODUCE REGIONALLY P = 0.7 LARGE REGIONAL DEMAND

INTRODUCE NATIONALLY

P = 0.7

LARGE DEMAND NATIONALLY

P = 0.71

LIMITED NATIONAL DEMAND

P = 0.29

DO NOT GO NATIONAL

LARGE NATIONAL DEMAND

P = 0.5

LARGE REGIONAL DEMAND

P = 0.2

LIMITED NATIONAL DEMAND

P = 0.2

LIMITED DEMAND

P = 0.3
For a large 'tree' the numerical calculations become excessive and recourse should be made to 'Dynamic Programming', which is essentially a mathematical theory of multistage decision processes. Mathematical models employing the principles of dynamic programming offer three tangible advantages:

* Economy in formulation with all possible outcomes covered.
* Readily adapted for computer solution.
* Readily extended. e.g. stochastic decision processes and adaptive control.

(iii) PROJECT SELECTION

Selection of the 'best' version of the project may not always be possible in the 'Project Analysis' step.

Thus, there may be a gap in the product range that needs to be filled and several possible technical solutions exist. (e.g. aerosol V liquid application!) Alternatively, there may be resource limitations depending on the requirements of other projects. Under these circumstances project formulation may culminate in a 'PROJECT SELECTION' model, in which the total resources available are allocated between several projects to give the highest total return. Naturally, versions of the 'same' project will be mutually exclusive. Linear programming and integer programming models have been developed to meet this need. Their major features are:
a) Selection between mutually exclusive project versions.
b) Several time periods are considered.
c) Marginal value of increasing or retraining staff or purchasing equipment is given.

iv) RISK ANALYSIS

Investment decisions are characterised by a high degree of risk. (e.g. the total market may decline or the product is superceded!) Unlike mistakes in inventory decisions, however, investment decisions cannot be corrected in a short period of time. Considerable effort has consequently been expended in developing mathematical techniques for evaluating the effect of poor estimates. Thus, benefit and cost distributions have been combined by means of the Monte Carlo technique, stochastic decision trees have been developed for the analysis of investment decisions and project selection models are available which allow probability distributions for benefits, costs and required resources. Management now have at their fingertips:

a) Expected return (NPV) of a project version
b) Probability distribution for the NPV
c) Sensitivity of the result to assumptions regarding the type of distributions selected.

Using concepts such as 'utility' and 'risk aversion' decisions may then be reached which reflect the individual managers' attitude to risk. Nevertheless,
risk analysis by means of mathematical modelling is one of the most difficult results to 'sell' to management.

So the question to be asked is: "Are we really doing our job well in this area of risk analysis?"

If half the effort expended in this field were devoted to reducing the total uncertainty (e.g. by buying information!) would management have greater confidence in our recommendations? I believe so!

The reduced variance would certainly be a major factor! A practical study of the accuracy of forecasts in novel projects is of interest in this connection (8). In general, the financial outcome is most sensitive to sales volume and selling price. Detailed analysis of the uncertainties associated with these variables is consequently justified during project formulation.

Another cause for concern is the common assumption that benefit and cost distributions are independent. Social costs and benefits are likely to be significantly correlated.

Mathematical modelling, then, while a major tool in the manager's armoury should not be used indiscriminantly.

PROJECT CONTROL

The need for expert project management in the face of inflation and increasing competition is generally accepted
Frequent re-allocation of resources (men, money, machines etc.) is necessary to offset unexpected delays, reversals and charges in strategy. Not surprisingly then, the development of improved network planning methods and predictive relationships between present status and final outcome is of paramount importance.

There are two basic approaches:

1. Use of criteria/checkpoints developed during project evaluation.

2. 'Hindsight exercises' on similar projects to identify critical factors, which are then monitored. (1)

Commonly used criteria are:

a) Time (e.g. CPM, PERT)
b) Cost (actual vs budget)
c) Technical progress.

However, due to the dynamic nature of the market place, it is likely that mathematical models incorporating a project schedule will soon supplant such primitive techniques by offering instantaneous readout of:

i) Cumulative added value
ii) Project payback period
iii) Potential queuing problems
iv) Skill shortages

Even in the research and development field where economic uncertainty is compounded with technical uncertainty, there have been considerable developments in Management Information systems (9) and planning tools. (10)
The creation and development of aids is an important contribution of O.R. scientists to management effectiveness. Management aids are generally readily accepted and may have one or more of several functions:

- i) Communication Aid
- ii) Diagnostic Tool
- iii) Control aid.

Essential considerations for the design of any planning aid are stated below:

1. Does it force a choice?
2. Does it give adequate information on the implications of that choice?
3. Is the information provided actionable?
4. Are there suitable criteria for evaluation purposes?
5. Is it simple to use and easily comprehended?
6. Is the 'visual impact' effective?

Choice of Aids:

Figure VIII demonstrates the use of a management aid for relating the most appropriate planning tool to the desired objective. Naturally, there is scope for new aids offering alternative combinations of benefits.

Uses of Management Aids:

Possible uses of management aids in the field of project evaluation will now be considered:

1. Ranking Cost and Benefit Classes:

   A plausible method of comparing the costs and benefits of multiple project outcomes is shown in figure IX. Where there are multiple classes of benefit and cost, the frequency with which each may occur could be useful diagnostic information.
RANKING COST AND BENEFIT CLASSES

FIGURE IX
<table>
<thead>
<tr>
<th>MANAGEMENT AID</th>
<th>BENEFITS</th>
<th>EARLIER RETURN ON INVESTMENT</th>
<th>TERMINATION OF UNPRODUCTIVE INVESTMENT</th>
<th>BETTER SCIENCE</th>
<th>IMPROVED EFFICIENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHECKLISTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NETWORKS</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CORRELATION CHARTS</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CASH FLOW DIAGRAMS</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>FUTURE MAPS</td>
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<tr>
<td>PROJECT SELECTION</td>
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</tr>
</tbody>
</table>

FIGURE VIII
2. **Ratio - Estimating:**
Graphical aids relating capital and operating costs to plant throughput.

3. **Cash Flow Diagrams:**
Diagrams showing **Payback time**, **Equivalent Maximum Investment Period** and the **Interest Recovery Period** are useful management aids for concerns whose main wish is to achieve a stable cash flow position.

4. **Intangible Benefits in Project Evaluation:**
The problem of including intangible benefits in project (version) selection is a very real one. There are two common approaches to overcoming the problem:

a) Assigning some monetary value to the 'intangible' items based on the minimum equivalent social benefit. Considerable experience would be necessary before this should be attempted.

b) Defining a profile of project benefits:
Management aids representing the benefit profile of each project version (see figure X) would permit rapid identification of that version giving the most desirable (pre-defined) combination of intangible benefits. Visual comparison is extremely valuable where a trade off is involved between total discounted benefits and 'intangibles'.
As the techniques used in project formulation increase in sophistication (e.g. simulation, serial correlation, adaptive forecasting), there will be a corresponding requirement for improved aids for presentation of the choices and results to management. Fortunately, the technology for graphical display of and interaction with computer output is now equal to the challenge, so it will no longer be necessary to design new aids on paper!
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Industrial research relies for a profitable outcome on the successful organisation, selection and synthesis of results from many sources, including specialist services. Inadequate consideration of ancillary service requirements can materially affect the productivity of research in such ways as:-

1. Project delays : Possible reasons are seasonal demand, high total demand in relation to the capacity available and inadequate job scheduling.

2. Biased project Selection : Ideas/strategies requiring specialist services may not reach the stage of overt consideration if such services have not been readily obtainable in the past.

3. Inadequate capability in some areas : Severe pressure on a section can lead to a short term position and the planning of future skills required may suffer.

4. Wasted resources : Can arise if the capacity of the service section is greater than the actual service requirement.
It is consequently important to determine the origin of demand on a service section and the uncertainty associated with this demand. Methods can then be developed for:

(a) Monitoring the situation continuously to identify long term pressures.

(b) Regulating the pattern of demand in a predetermined way.

(c) Determining a proper size for the service section.

(d) Improving the efficiency of the service system.

The particular study described here concerns the instrument service requirements of URL/PS.

INSTRUMENT SERVICE CHARACTERISTICS

A preliminary survey of management opinion (scientific sections) regarding the state of instrument service was first made by questionnaire (Figure 1). It revealed acute competition for instrument service, corroborated by the extent of the outstanding job load.

The reasons appeared to be:

(a) Rapidly increasing maintenance load.

(b) Trend to more sophisticated instrumental methods in the cause of better reproducibility and control.
Examples of increases in required electrical parameter accuracies reported (*) for common types of test equipment include the following:

<table>
<thead>
<tr>
<th>INSTRUMENT CLASS</th>
<th>TYPICAL PARAMETER ACCURACIES (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1950</td>
</tr>
<tr>
<td>Oscilloscopes</td>
<td>0.25</td>
</tr>
<tr>
<td>DC Power Supplies</td>
<td>0.1</td>
</tr>
<tr>
<td>Voltmeters</td>
<td>0.1</td>
</tr>
</tbody>
</table>

(c) High level of technical competence stimulating requests for advanced feasibility studies.

(d) A rapid increase in research personnel unaccompanied by a corresponding increase in the size of the instrument shop.

(e) The absence of a rational mechanism for allocating priorities to requests for instruments.

The limited data available supported these opinions. On the basis of this preliminary analysis certain recommendations were made:

I Scientist responsibility for the practicability of the final instrument design.

II A job progressing system with information recall facilities be installed.
III Greater use of contract servicing.
IV Wider use of preventative maintenance.
V Introduction of a Queue Ordering System.

These measures have been implemented. The expected benefits were:-

I More precise instrument specifications. i.e. ultimately more 'successful' instruments.
II Better financial control and better planning.
III Release of skilled manpower for instrument development work.
IV Control of the total maintenance load.
V Improved utilisation of labour by suitable choice of queue ordering formula. e.g.
   (a) The potential usefulness of construction kits is likely to be investigated more thoroughly.
   (b) The modular principle of construction may be adopted more frequently.
   (c) More interest may be shown in sub-assemblies that can be obtained externally.

(*) 'R&D Equipment Management - A New Functional Area' by W.R. Amesbury Jr., Eleventh Annual International Meeting of the Institute of Management Sciences, Pittsburgh, U.S.A.
(d) Interest should be stimulated in the activities of SIRA, the NPL and other specialised groups in the field of metrology to supplement the expertise of the instrument section and thereby reduce the experimental period involved in 'feasibility jobs'.

(e) Laboratory management can obtain a more realistic picture of the true pressure on the instrument shop.

EXPERIENCE IN OPERATING THIS JOB CONTROL SYSTEM

1. Well received by the instrument shop/scientists, i.e. improved communications.

2. Providing useful management controls (queue order, total job load outstanding).

3. Section managers have generally welcomed the information provided (Figure II). Often leads to post-mortems of job delays or heavy expenditures.

4. Low operating cost (ca $140 p.a. for the basic service).

ANALYSIS OF INSTRUMENT SERVICE DATA

(i) Figure III shows the annual revenue expenditure by each scientific division for the years 1965-1967 plotted against the labour component of this expenditure.

(ii) For the three years 1965-1967 there also appears to be a correlation between the number of qualified staff and
the proportion of the laboratory budget spent on instrument service (c.f. Figure IV). It is thus possible to say what resources will need to be allocated for instrument service to maintain the current level of service.

(iii) The outstanding job load fell considerably after the introduction of the queue ordering system. Part of the fall can be attributed to concomitant organisational change, however. More significantly, there is no evidence that the range of instrument job submitted to the instrument shop has been adversely affected.

SUMMARY OF ACHIEVEMENTS TO DATE

1. The queue ordering system is operating satisfactorily and information is now being generated, which will enable future needs to be assessed more precisely.

2. Instrument completion dates can now be projected.

3. Closer financial control of instrument job progress is being exercised by job sponsors/section managers.

4. The instrument service data for 1965-1967 has been shown to have a definite structure. The size of the instrument shop can be projected in the short term from a knowledge of the laboratory budget and proposed staff recruitment.

5. A scheme is in operation to control the total maintenance load on the laboratory.
6. Experience in operating the current system has revealed other ways in which the effectiveness of the instrument shop might be improved, e.g.

(a) Redistribution of the resources within the instrument shop between the various functions.
(b) Reduction of the administration/clerical burden using modern data processing techniques.
(c) Value analysis of instrument parts.

BENEFITS REALISED TO DATE

(i) Savings in management time
(ii) Administrative savings
(iii) Improved service
(iv) Identification of future data requirements.

FUTURE DEVELOPMENTS

1. Further analysis of the data to assist management to plan the most effective allocation of resources between the three functions; instrument design, instrument development and maintenance.

2. Extension of the job progressing system to give research management more effective control. The proposed system will be described in another paper.

3. Simulation studies of the influence of the queue ordering formula on the pattern of demand for instrument service.
SUMMARY

In this paper I have attempted to describe,
(a) The reasons for determining specialist service requirements.
(b) The approach adopted.
(c) The underlying structure of the available data.
(d) Preliminary results on the influence of a queue ordering formula on the job queue characteristics.
(e) The specific benefits to be derived from the implementation of a job control system.
<table>
<thead>
<tr>
<th>QUERY</th>
<th>No.</th>
<th>RESPONSE</th>
<th>SUPPLEMENTARY COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the projected use of the instrument shop for 1967 still hold?</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is the future pattern of work (demand) likely to be similar to that in 1965-1966?</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extent of latent demand: [n \text{ Fold} \times (\text{Current jobs with the workshop})]</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is scientific choice affected by the limitation on workshop capacity?</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are you satisfied with the present arrangements for obtaining service from the workshop?</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If the reply to (5) is yes, would there be any objection to the introduction of a Queue Ordering System?</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Should job requisitions for more than 5 hours labour require the signature of the Section Manager?</td>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
INSTRUMENT SERVICE SUMMARY FOR SECTION MANAGERS

SECTION: PHYSICAL CHEMISTRY  LOCATION NUMBER: 948

INSTRUMENT SERVICE RECEIVED DURING AUGUST 1968

<table>
<thead>
<tr>
<th>MAINTENANCE/SUNDRIES</th>
<th>PROJECT WORK</th>
<th>TOTAL SERVICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.25</td>
<td>4.71</td>
<td>6.96</td>
</tr>
</tbody>
</table>

Project Work includes instrument development work on revenue and capital account. The units of effort recorded here are man-weeks.

Available effort this month = N man weeks

JOBS IN THE INSTRUMENT SHOP

<table>
<thead>
<tr>
<th>JOB NUMBER</th>
<th>TITLE</th>
<th>SPONSOR</th>
<th>LABOUR</th>
<th>MAT.</th>
<th>STATUS</th>
<th>Q POSN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1519</td>
<td>GLC INLET SAMPLE SYSTEM</td>
<td>G.N. HURD</td>
<td>35</td>
<td>355</td>
<td>L</td>
<td>1</td>
</tr>
<tr>
<td>1522</td>
<td>TWO PADDLE STIRRER SYSTEM</td>
<td>A. GRIFFIN</td>
<td>45</td>
<td>20</td>
<td>L</td>
<td>8</td>
</tr>
</tbody>
</table>

The following letters have been used to designate job status.

D = Design stage:  Q = Waiting for quotations:  X = Capital applied for but not yet sanctioned:

M = Awaiting materials:  L = Waiting for labour:  A = In Abeyance pending confirmation:

C = Completed last period.
GRAPH OF STAFF UNITS V PROPORTION OF LABORATORY REVENUE BUDGET TO BE SPENT ON INSTRUMENT SERVICE

WEIGHTED SCIENTIST UNITS

FIGURE IV
GRAPH OF ANNUAL REVENUE EXPENDITURE ON INSTRUMENT SERVICE BY DIVISION & LABOUR COMPONENT OF THAT EXPENDITURE

TOTAL REVENUE EXPENDITURE (,000)

FIGURE III

LABOUR ELEMENT (,000)
ESTIMATING OBSOLESCENCE IN AUTOMOTIVE PARTS & ACCESSORIES


1. INTRODUCTION

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1. INTRODUCTION

1.1 STATEMENT OF PROBLEM

In Ford Australia program planning and budgeting is a well accepted mode of planning and control. In this context quantitative cost benefit analysis for evaluation of competing alternatives is practiced by finance staff groups examining facility expansion, marketing and product planning programs. The notion that a cost benefit approach has specific application to operational situations is not so generally accepted.

We have chosen to model the inventory case history described here in a way which gives visibility to the costs of operational judgements. The models have been incorporated in a computer based inventory management system which has realised substantial savings in investment. The balance of the work is incomplete to the extent that the benefits resulting from prompt service have not received similar scrutiny.

1.2 BACKGROUND

The ability to provide ready replacement of automotive spare parts is considered to be vital to ensure customer satisfaction which in turn is expressed in new vehicle purchase.

This policy is reflected in the vast range of parts carried in inventory, a willingness to supply for many years after the vehicle is last manufactured and to service better than ninety percent of requests from stock.
Many parts and accessories exhibit fashion demand, many involve substantial setup and tooling costs compelling infrequent or all-time manufacture early in the lifetime of the item. These policy pressures have tended to spawn replenishment procedures, which fail safe by overstocking. When these procedures are coupled with the demand uncertainties parts obsolescence is inevitable.

In order to realise the benefits of modelling parts and accessories' demand histories, the models have been incorporated into a mechanised obsolescence system along with company rules for categorising obsolescence conditions. The system:

a) Provides reports to enable the most efficient identification and removal of surplus stock.

b) Provides an accurate valuation of the surplus stock for profit analysis.

c) Facilitates avoidance of future surplus by ensuring that ordering actions are reviewed and that all-time requirements are not exceeded.

1.3 BENEFITS

The benefits achievable through the accurate estimation of obsolescence and all-time requirements over the full range of parts and accessories stocked in a warehouse can be summarised as follows.
1.3.1 REDUCED STOCK-HOLDING COSTS

Reduced stock-holding costs due to reduction in:

a) Interest loss on capital previously held in inventory.

b) Warehouse space used to the extent that this could justify delay of capital expenditure on warehouse expansion.

c) Administration costs; by removing some parts from day-to-day records and elimination of double counting of obsolete parts at annual stocktaking and handling costs.

d) Insurance.

1.3.2 INCREASED REVENUE

Increased revenue due to:

a) Parts sold as scrap.

b) Parts sold cheaply in special sales programs.

c) Parts sold now which, in future, may become unsaleable.

d) Taxation benefit by being able to accurately value irretrievable obsolescence and do so promptly.
2. MODELLING OF PARTS' DEMAND

2.1 GENERAL FORM OF A PART'S LIFETIME

On analysing extensive samples of parts' demand history taken from every category of inventory, we have found that the lifetime of a part goes through three distinct phases. The duration of each of these phases varies considerably from part to part. These phases are depicted in figure 1.

PHASE I - is usually a short period in which demand increases rapidly; in limiting cases this phase does not even exist, as demand hits a peak in the first year of selling and declines thereafter.

PHASE II - is the stage when there is essentially constant demand for the part; with no apparent trend and only random variation about a mean.

FIG. 1 TYPICAL PART LIFETIME
PHASE III - which is the stage we are most concerned with, may take any one of many declining forms, depending on the use, characteristics and model applications of the part.

There are two distinct categories of parts to be modelled, each requiring a different approach.

a) Parts with extensive recorded demand history for which an obsolescence condition is most likely.

b) Parts with little or no demand history available. Frequently these are new parts which we would not yet expect to be obsolete. Nevertheless, by making good initial buys for these parts, future obsolescence can be minimised. Some of these parts are one-time buy (or build) parts for which an estimate of all-time requirements, based on the life patterns of similar categories of parts, can be very valuable.

2.2 MODELLING DEMAND WHEN SUFFICIENT HISTORY IS AVAILABLE

2.2.1 DETECTION OF PHASE III CONDITION

A part's history needs to be firstly examined to confirm that it is in Phase III of its life, the tapering off period. The part is submitted to the checks outlined below and if it fails any of them it is by-passed and modelled according to the approach described in Section 2.3.
a) The part must have at least four years of demand history for the fitting techniques to be appropriate.

b) If the ratio of current demand to total demand to date is 2% or less, vigorous activity on this part is extremely doubtful and it can be safely considered to be in Phase III of its life.

c) The demand history should not show an upward trend, as the part concerned would clearly not be in Phase III of its lifetime.

d) It must have at least three years of demand history beyond the break-point, or year in which the pattern apparently begins to fade.

2.2.2 MODELLING A PHASE III DEMAND PATTERN

After detailed study of many hundreds of parts' histories in Phase III condition, three basic modes of decay have been detected, rapid, slow, or medium.

Further analysis revealed that these patterns become more pronounced when the logarithms of the demand data are plotted against the logarithms of the years for which the demands were recorded. Three families of mathematical curves the ellipse, the exponential and the parabola best describe the rapid, slow and medium decay modes.
For example -

For demand data with a "medium" declining pattern, as shown in Fig. 2, the parabolic model is used.
The general form of the parabola is: 
\[ y = y_0 - ax^2 \]

now, since the curve passes through the point \((x_0, 0)\), solving for the constant "a" yields: 
\[ a = \frac{y_0}{x_0^2} \]

and thus the parabola has the form: 
\[ y = y_0 - \left(\frac{y_0}{x_0^2}\right)x^2 \]

When used for all-time requirement forecasting, the parabola relates the logarithm of demand to the logarithm of time for all years after the year of peak demand for a part. Therefore, if "s" represents the forecasted demand over time "t", the demand - time relationship is: 
\[ \log s = y_0 - a (\log t)^2 \]

or, equivalently: 
\[ s(t) = 10^{y_0 - a (\log t)^2} \]

now substituting for "a" gives: 
\[ s(t) = 10^{y_0 - \frac{y_0}{x_0^2} (\log t)^2} \]

hence: 
\[ s(t) = 10^{y_0 \left( 1 - \left(\frac{\log t}{x_0}\right)^2 \right)} \]

Where:  
- \( y_0 = \log \) (demand in peak year)  
- \( x_0 = \log \) (year of zero demand)
The value of \( x_0 \) is varied in yearly increments for fifteen years, say, beyond the year in which the last demand was recorded. This gives fifteen different parabolae. The best is obtained by choosing the one which gives the smallest error-term. The error-term is calculated as the mean absolute deviation between forecast and actual demands.

In general a similar procedure is repeated for Phase III of a part's demand history using in turn elliptic, parabolic and exponential decay models. The respective demand-time relationships are given below:

- \( s(t) = 10y_0/x_0 \sqrt{x_0^2 - (\log t)^2} \) \quad \text{Rapid Decay}
- \( s(t) = 10y_0(1 - ((\log t)/x_0)^2) \) \quad \text{Medium Decay}
- \( s(t) = 10y_0(1 - t/x_0) \) \quad \text{Slow Decay}

The model chosen for demand projection is that which gives the least mean absolute deviation.

This function may then be used to calculate annual projections until the demand drops to zero. In practice, however, projections are more frequently made to a cut-off level determined by economic considerations.

The all-time requirements of the part being studied are obtained by summing the annual demand projections from the present up to the cut-off point.
A part is obsolete if the inventory exceeds all-time requirements. If, however, the all-time requirements exceed the inventory an all-time buy could be appropriate for the part.

An all-time buy is usually made for a part when the difference between the inventory and the all-time requirement approaches some economic order quantity. At this stage a final order, or all-time buy, is made based on these economic considerations. This generally occurs in the latter half of the service period of a part.

There are large numbers of parts, usually made in plant, where large investments are involved in tooling and dies. In these cases the all-time buy, or build, quantity has to be decided early in the life of a part, and may even be a case of a one-time buy or build.

### 2.2.2.1 Example of Modelling Procedure

The following is a typical part in Phase III of its lifetime, with portions of a computer analysis reproduced below.

**PART: VALVE ASSEMBLY C3AZ 9352 A**

**Demand History Beyond Breakpoint**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>DEMAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>284</td>
</tr>
<tr>
<td>1968</td>
<td>176</td>
</tr>
<tr>
<td>1969</td>
<td>118</td>
</tr>
<tr>
<td>1970</td>
<td>76</td>
</tr>
</tbody>
</table>

Ending inventory is 6330 pieces

**Mean Absolute Deviations**

<table>
<thead>
<tr>
<th>MODEL</th>
<th>ABSOLUTE DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELLIPSE</td>
<td>10.279</td>
</tr>
<tr>
<td>PARABOLA</td>
<td>7.366</td>
</tr>
<tr>
<td>EXPONENTIAL</td>
<td>8.525</td>
</tr>
</tbody>
</table>

... Best fitting model is the parabola ...
## ALL-TIME BUY/OBSOLESCENCE ANALYSIS FOR VALVE ASSEMBLY

**PART NUMBER:** C3AZ 935 A

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ACTUAL DEMAND</th>
<th>PROJECTED DEMAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>284</td>
<td>284</td>
</tr>
<tr>
<td>1968</td>
<td>176</td>
<td>203</td>
</tr>
<tr>
<td>1969</td>
<td>118</td>
<td>121</td>
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<tr>
<td>1970</td>
<td>76</td>
<td>73</td>
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<td>1971</td>
<td></td>
<td>46</td>
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<td>1972</td>
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<td>1973</td>
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<td>20</td>
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<td>1974</td>
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<td>1975</td>
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<td>10</td>
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<td>2</td>
</tr>
<tr>
<td>1982</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1983</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**EXPECTED ALL-TIME REQUIREMENTS = 145**

**PREVIOUS ENDING INVENTORY OF 6330**

**EXCEEDS ALL-TIME REQMTS OF 145 BY 6185 UNITS**

If the cost-price of each part is 20¢, say, then obsolescence of $1200 is implied. Analysis of this sort suggests that obsolescence in a warehouse of 100,000 stock lines can be immense. By analysing a representative sample of stock categories we have been able to estimate quickly the order of magnitude of the obsolescence and make a rough valuation of the savings achievable before attempting to model the full range of parts.
PLOTS OF THE BEST CURVES ARISING FROM THE ASSUMPTION OF
FAST, MEDIUM AND SLOW DECAY MODES FOR PHASE III OF DEMAND
FOR A VALVE ASSEMBLY UNIT
2.3 MODELLING DEMAND WHEN INSUFFICIENT HISTORY IS AVAILABLE

2.3.1 GENERAL PROBLEM OF NEW PARTS

From the experience obtained in modelling representative samples of demand history from the total inventory, we found it possible to specify the demand pattern of an auto part or accessory with reasonable accuracy, using three parameters.

These are:

a) The year in which peak demand occurs.

b) The value of the peak demand

c) The type of decay in demand after the peak demand.

For parts with insufficient or inappropriate data for fitting, assumptions can be made about the three parameters and the peak value for demand can be declined exponentially to give a conservative estimate of future requirements. In this approach we assume that peak demand is reached immediately the part is stocked and that this demand is maintained until Phase III of its lifetime. This crude approach contains substantial concession to the stocking enthusiast.

Prior to this, lacking advance information on the order of magnitude of expected demands, especially for new parts, the task of making realistic initial buys for large numbers of these parts has proved extremely difficult. In order to fail safe the tendency has been to grossly overstock. The extent of this overstocking, which can be compounded by mechanised ordering systems, is often only realised when Phase III
of parts' lifetimes are entered and by this time huge penalties have been incurred for a number of years.

2.3.2 ESTIMATION OF DEMAND PARAMETERS

We have found that the three parameters needed to model the demand pattern of a part depend on the function of the particular part in a vehicle. By observing groupings of parts with considerable history which belong to various functional categories, it is possible to find characteristic values of the parameters for each functional category. Thus, by knowing the category to which a new part belongs, it is possible to make useful assumptions about its expected lifetime demand pattern.

Consider two such function categories by way of example.

CATEGORY 1

Functional parts, are those parts whose function is so important to the operation of the vehicle that we must retain them in stock for a fairly lengthy period even though the demand has become negligible.

Consider a car, truck or tractor that is seven years out of production, i.e. 7 years since the last of that model was assembled. For such a vehicle a customer expects to be able to be supplied with:

Brake, steering and engine components
Mufflers and pipes
Transmissions gears and bearings
These then are what we consider to be functional parts. For such parts we apply a gradual exponential decline to bias the system toward ensuring service.

**CATEGORY 2**

On the other hand, if the customer needs the following parts:

- Ornaments and mouldings
- Body panels and glass
- Fenders, boot lid and hood
- Chassis brackets, fuel and brake lines

They can be repaired, improvised, obtained from wreckers or neglected. These non-functional parts tend to reach peak demand quickly and then fall off quickly, so we apply a rapid exponential decline after a relatively short period of peak demand.

Thus by categorising new parts according to their function we can define and estimate:

a) \( z_1 \) - the year in which peak demand occurs

b) \( z_2 \) - the decay factor describing the type of decline in demand after peak demand has been reached.

c) \( \text{peak} \) - peak demand expected for a part

**2.3.3 MODELLING DEMAND**

Having estimated the parameters for the type of part under consideration we model the demand as follows:
a) If the year of peak demand has passed, i.e., if the current year $Y_{\text{now}} \geq Z_1$, then we calculate the demand $S$ as follows:

$$S(t) = S_{\text{peak}} \times 10^{-Z_2 \left( t - Z_1 \right)}$$

b) If the peak demand has not yet been reached, i.e., if the current year $Y_{\text{now}} < Z_1$, then we calculate the demand $S$ as follows:

$$S(t) = S_{\text{peak}}$$

This procedure is illustrated in Fig. 4 below.

![Diagram](image)

**Fig. 4** DEMAND-TIME RELATIONSHIPS

Once again, the all-time requirements of such parts are obtained simply by summing the annual demand projections from the present time up to the cut-off point.
3. A MECHANISED OBSOLESCENCE SYSTEM

3.1 STATEMENT OF REQUIREMENTS

The task of screening, checking functional use, fitting of demand patterns and reporting on 100,000 stock lines is manually infeasible because of timing restrictions. Manual systems of obsolescence estimation must necessarily be restricted to samples of the total number of stock lines with extrapolation of the obsolescence over the total inventory. One of the most unsatisfactory aspects of such a scheme is that it is designed to fail safe by overstocking.

In order to achieve effective use of the modelling techniques described they have been incorporated into a computer based inventory control system which treats every part stocked. Having obtained estimates of all-time requirements it is possible to identify and value obsolescence and potential obsolescence. Action can then be taken to reduce surplus and to prevent future surplus conditions from arising by tailoring orders in line with annual demand projections and all-time requirements.

3.2 SYSTEM DESIGN

The models described have been incorporated into a system which is made up of three phases:

144.
3.2.1 DATA EDITING PHASE

In this phase an extract file of historical demand data is prepared from a magnetic tape Parts' Master File. At the same time the following edit functions are performed for each part:

a) The remaining service policy period is calculated. The service policy period for an automotive part or accessory is the number of years for which the company commits to supply customers with the item. It is dependent on the vehicle models the item is used on and is purely a matter of management policy. The remaining service policy period is thus the number of years left before the service policy period expires. Stocking of a part may, however, continue if the part is still selling well, even though the remaining service period is nil.

b) Parts are categorized according to product and function codes and corresponding modelling parameters are attached.

c) A check is made to see if the part has already been classified as obsolete or if there is no remaining service policy period. These parts are flagged, since there is no point in modelling their demand patterns.

145.
d) The method of modelling appropriate to the part concerned is determined by checking if the part is new and whether there are a sufficient number of years of demand history available.

3.2.2 DECISION LOGIC

The decision logic is incorporated in two modules, the first being run annually or biannually, the second monthly.

3.2.2.1 ANNUAL LOGIC MODULE

The computer programs in this module carry out three main tasks:

a) DETERMINE ALL-TIME REQUIREMENTS

The all-time requirements are calculated, according to the modelling techniques described, subject to three economic cutoff criteria, i.e. yearly projections of demand should cease when -

i) An annual demand projection falls below a specified number of pieces.

ii) An annual demand projection falls below a specified number of dollars in value.

iii) The service policy period has expired.

It is our policy to estimate the all-time requirements for a part by taking the largest value obtained subject to the above restrictions.
b) CATEGORISATION OF PARTS INTO SURPLUS TYPES

To give visibility to the nature of the obsolescence encountered, each part is allocated to a surplus category.

i) Parts which have already been classed as obsolete. Any stock on hand for such a part is surplus.

ii) Parts which have no remaining service period. Any stock on hand for these parts is surplus unless there is significant demand.

iii) Parts for which the remaining service period is less than a specified period. No further orders should be placed for these parts, the surplus being the stock on hand minus the all-time requirements.

iv) Parts which have a substantial remaining service policy period but which have an all-time requirement less than a specified level. Such parts should only be ordered on demand, if practicable, and any stock on hand junked.

v) Parts which are in Phase III of their lifetime with an established demand pattern and a substantial remaining service period. Where stock on hand exceeds all-time requirements the difference is surplus.
vi) New parts and parts with little demand history. These would not yet be expected to have any surplus, but any positive difference between stock on hand and all-time requirements is declared surplus.

vii) All parts for which all-time requirements exceed stock on hand. In these cases there is no surplus. If the magnitude of the difference, or all-time buy is small then, taking account of time lags associated with use of annual demands, these parts are potentially obsolete and review is needed before any further orders are placed.

c) UPDATE OF THE PARTS MASTER FILE

In this section of the annual decision logic the Parts Master File is updated with the all-time requirement figures. This makes the all-time requirement accessible to the inventory review and ordering system which produces exception reports for parts where forecast orders exceed all-time requirements.

3.2.2.2 MONTHLY LOGIC MODULE

This set of programs enables junking decisions, made on the basis of the reports produced by the annual logic, to be executed month by month and recorded.
3.2.3 REPORTING LOGIC

3.2.3.1 ANNUAL REPORTS

a) MASTER LIST

This report shows each part number on the Parts Master File with accompanying detail such as:

- Year by year projections of demand
- All-time requirements
- Stock on hand
- Remaining service period
- Suggested surplus
- Surplus type
- Space left for handwritten comments to be entered

This document is used as a master reference list in conjunction with summary reports and provides a permanent record of the reasons for junking or retaining parts.

b) SURPLUS REVIEW REPORTS

The reports are produced for each surplus type and the parts within a surplus type are listed in order of descending obsolescence value. Recorded against each part is:

- All-time requirements
- Stock on hand
- Cost price
- Suggested surplus
Value of surplus at cost price
Running total of the value of surplus within each surplus type

This report is an important aid in rapidly identifying and valuing obsolescence prior to commencing a junk and liquidation program.

c) ALL-TIME BUY REPORT

This report lists all parts for which all-time requirements exceed stock on hand, in ascending sequence of all-time buy value. The detail shown against each part is similar to that shown in the Surplus Review Reports with the addition of:

- All-time buy quantity
- All-time buy value at cost price

This report is useful in detecting further obsolescence and potential obsolescence as well as all-time buy, and one-time buy situations.

3.2.3.2 MONTHLY REPORTS

a) WAREHOUSE JUNK/LIQUIDATION LISTS

This report is produced in warehouse location sequence, and shows against each part:

- Warehouse location
- Quantity to be held
- Expected quantity to be junked
- Space left for handwritten comments

These reports enable rapid removal of surplus stock.
b) JUNK/LIQUIDATION SUMMARY REPORT

This report has the same information as appears on the Surplus Review Reports, except that an indication is also given regarding:

- Value of stock junked or liquidated to date
- Percentage of total obsolescence removed to date

This report indicates the progress to date of a junk and liquidation program.

3.3 EFFECTIVE USE OF THE OBsolescence SYSTEM

3.3.1 TIMING OF THE COMPUTER RUNS

a) ANNUAL LOGIC MODULE

The annual logic module is being run twice a year in order to achieve maximum cost effectiveness.

RUN 1 - The first run is made on the 1st of January. This enables the latest year-end demand figure to be used in the forecasts of all-time requirements, with a corresponding improvement in the accuracy of obsolescence estimates.

RUN 2 - The second run is made immediately after annual stock-taking procedures have been completed to comply with audit requirements. This has the advantage that the...
MACRO FLOWCHART OF OBSOLESCENCE SYSTEM

**An annual logic**

**December Logic**

1. **Run Parameters**
2. **Parts Master File**
3. **Data Edit Phase**
   - **Parts Master Extract**
   - **Parts Master File**
4. **Processing via Decision Logic**
   - **Obsolescence Master File**
   - **Updated Parts Master File**
5. **Report Generation**
   - **All-Time Buys**
   - **Surplus Review**
   - **Master List**

**Monthly Logic**

6. **Update of Obsolescence Master File**
7. **Junk/Liquation Decisions**
8. **Junk Summary**
9. **Junk/Liquation Lists**
10. **Obsolescence Master File**
11. **New Obsolescence Master File**

**Annual Logic**

12. **Image**
most up to date and accurate stock counts are used in the calculation of obsolescence. Also, since the status of parts can change unexpectedly in the space of six months, some of the results published in the first run may be invalidated. For example, with the release of a new model a current part may also be applicable to the new vehicle, in which case the part would certainly not be expected to be obsolescent. Or a part, previously in Phase III of its lifetime, may suddenly have a demand as a component in a newly created kit which has considerable demand.

Thus by running this logic module biannually the maximum effectiveness is obtained from the system.

b) MONTHLY LOGIC MODULE

This module is run monthly since the performance of departments and special projects within departments in the company is measured monthly in terms of performance to budget. Thus a monthly run -

- Enables management to easily assess the progress to date and performance to budget of a junking program
- Enables stock analysts to review sufficient parts to make a computer run economical.
Provides stock clerks with a substantial volume of junk and liquidation lists to work with in the following month.

3.3.2 REPORT INTERPRETATION

In order to achieve full cost effectiveness in a minimum of time with existing warehouse staff the suggested order of review and action is as follows:

1. High priority obsolescence
2. Further obsolescence
3. Avoidance of future obsolescence
4. Review of low-value obsolescence

3.3.2.1 HIGH PRIORITY OBsolescence

The high value obsolescence over parts in surplus types (i), (ii), (iii), and (iv) as shown on the Surplus Review Report, may be junked with little or no review action since they are respectively:

1. Obsolete already
2. Have expired service policy periods
3. No further demand possible for them
4. Buy on demand parts

The question of dealing with parts having low obsolescence value is treated later as a matter of lower priority. This is because the returns obtained from junking these parts is poor.
3.3.2.2 FURTHER OBSOLESCENCE

a) Firstly the high value obsolescence over parts in surplus types (v) and (vi), as shown in the Surplus Review Report, is reviewed and junked if appropriate. These parts, however, require more human judgement since they are parts —

- Which are in Phase III of their lifetime but still have demands above cutoff levels,

or

- Which are new parts with a considerable service period ahead of them

Thus, before the suggested surplus quantities can be junked, review is needed to ensure that no unexpected demands are anticipated in the future.

b) Further obsolescence is also to be found by reviewing parts in the low value section of surplus type (vii), as shown in the All-time Buy Report. These are parts, for which all-time requirements only just exceed stock on hand, which on a human judgement basis are generally obsolete.

3.3.2.3 AVOIDING FUTURE OBSOLESCENCE

Future obsolescence can be avoided in two main ways:
(a) By stopping the computer from ordering any parts of surplus types (i) through (iv), and (vii); unless otherwise indicated on the basis of manual review. These are parts which are obsolete already, have expired or nearly expired service policy periods, or are buy on demand parts.

(b) By anticipating which parts are about to become obsolete in the near future, and tailoring further orders in line with all-time requirements. These parts are to be found in the medium value section of the All-time Buy Report — surplus type (vii).

3.3.2.4 REVIEW OF LOW VALUE OBSOLESCENCE

Disposal of parts with a low value of obsolescence presents a problem in terms of cost effectiveness. The cost of reviewing and junking such parts is often greater than any revenue which might be obtained from their disposal. Such inventory is usually left in the warehouse and classed as irretrievable obsolescence for taxation purposes.

So before any special program is eventually initiated to remove such parts from the warehouse the following criteria are applied to justify removal action:
Ensure that the parts are in categories which have no chance of ever having any further demand, i.e. parts in surplus types (i), (ii) and (iii). Parts in other surplus types will shift to these categories in subsequent runs of the system; so until then they are not really worth reviewing.

Ensure that the aggregate value merits disposal action.

Review the warehouse space or "cube" taken up by these parts, as space is always at a premium for new parts which are continually being added to stock.

3.3.3 SUMMARY

Through the use of mathematical modelling and computers it is thus possible to estimate lifetime demand for each part on a Parts Master File consisting of, say, 100,000 entries for a negligible cost in comparison with the savings which can be achieved.
1. GENERAL COMMENTS

I would like to begin by emphasising that the operations research techniques used in designing, analysing and improving transportation systems cover a very wide spectrum. Applications range from comparatively simple techniques to optimise specific operations up to complex transportation studies at the regional or national level. Naturally the cost of such studies varies accordingly and may be anything from a few hundred dollars to a hundred thousand dollars. What I intend to do in this paper is to give some idea of the scope of applications by reference to four case histories.

The case studies are four "levels" of application. The first is at what may be called the microscopic end of the scale and represents the simple optimisation of a specific operation where the results are directly measurable dollar savings to the client.

At the second level of application, represented by the second case discussed in this paper, there are directly measurable cash savings but there are, in addition, many savings in terms of improved organisation which are hard to quantify.

The third study is at the level of management decision making where projects must be scheduled to give the maximum return from given investment of money and other resources. This is a matter of making best use of a given level of resources rather than any direct saving of money.

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Finally there is what may be termed the macroscopic situation where regional transportation planning is involved. A study of this type is the fourth case history. The aim of this type of study is to assist in the formulation of policy and the benefits obtained from the correct policy decisions are immense.

Let us now look at the case studies keeping in mind the general comments made above.

2. CASE STUDY 1: VEHICLE FLEET INSURANCE

This particular study was undertaken on behalf of a company which operates large fleets of vehicles in all States. It was undertaken at the time when the new driver rating system was introduced by insurance companies. The problem posed was:

"When is it economically best for the company to meet the cost of an accident themselves rather than claim on the insurance company and thereby increase future premiums?"

The solution lay in the development of a simple mathematical technique to provide a guide to the decision maker. The important factor to be held in mind is that claim decisions made in one year affect premiums paid in subsequent years. For example, consider the case of a driver on rating 6 who has an accident. The following table shows his rating over the next six years assuming that he has no further accident claims:

<table>
<thead>
<tr>
<th>Year</th>
<th>Accident Claimed</th>
<th>Rating</th>
<th>Accident Not Claimed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thus it will be six years before the premium paid by the driver who claimed is on a par with that of the driver who did not claim. Thus, the aim must be to minimize the total cost of accident damage paid for by the operating company and premiums paid to the insurance company.

Consider a simple example.

Suppose we have 100 drivers of whom 40 are expected to have accidents in any year. Suppose also that 10 accidents cost less than $50 in repairs, 10 between $50 and $100, 10 between $100 and $200, and 10 more than $200.

If the company strategy is to claim on accidents costing more than $100 then there would be 20 driver claims per year.

Assuming that the accident pattern remains constant over succeeding years then the distribution of drivers on different ratings would be as follows:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>51</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
<td>21</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>32</td>
<td>13</td>
<td>12</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>9</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The table becomes reasonably stable after five years. Similar tables may be constructed assuming different claim levels and a total cost curve may be plotted similar to that shown in Figure 1.
Examination of the curve produced enables the company to ascertain, firstly, whether or not an optimum claim strategy exists and, secondly, what it is.

In order to apply the technique it was necessary to know:

(a) the number of drivers on each rating;
(b) company accident statistics, i.e., number of accidents and cost distribution;
(c) premium structure, e.g., metropolitan and country rates, excess for young drivers, variations for vehicle types, premium discounts for given "excess" values.

This information was available from operating company and insurance company records and the technique was applied to fleet operations. It was demonstrated that after three years of operation the optimal strategy reduced total costs from $103,000 to $79,000 per annum.

3. CASE STUDY 2: STAFF ROSTERING

The management of any organisation which employs shift workers will be aware of the problems of staff rostering. Broadly speaking the problems generally resolve themselves into producing a roster which minimises penalty payments, meets the provisions of the particular award and is acceptable to staff. This latter requirement is sometimes overlooked, but a roster which does not distribute overtime evenly between staff and which fails to group days off into twos, threes, etc., or which introduces widely divergent daily starting times for a given person can be a cause of industrial strife which can prove very expensive. In large organisations such as public transport operators who have a thousand or more shift workers the rostering problems become a major headache and many highly skilled staff are required to set up and
maintain the rosters. The particular case study discussed here was undertaken on behalf of just such an authority and covered some 920 drivers and conductors.

The process of staff rostering is undertaken in three phases:

1. Run cutting.
2. Pairing of Shift Parts for Broken Shifts.
3. Construction of Rotating Roster.

Run cutting consists of defining vehicle runs to meet the known demand and cutting these runs into pieces of work which will form an acceptable shift part. These shifts parts must meet the requirements of the award and must include allowances for signing on and off, travelling to pick up points, etc. Because of the double peak in the demand curve the shifts fall into three types -

(a) morning straight shifts;
(b) late finishing straight shifts; and,
(c) morning and afternoon parts of broken shifts.

The pairing of parts of broken shifts, that is combining a morning part and an afternoon part to form a complete shift, is very important since there is considerable scope for direct savings in terms of minimised penalty payments. In the particular case under discussion the problem was formulated as an assignment problem and a standard operations research method was modified to give the required solution. An example of the improvement obtained is shown in the following table:

<table>
<thead>
<tr>
<th>Depot No. of Shifts</th>
<th>Penalty Cost (mins)</th>
<th>Saving (Mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original Roster</td>
<td>Optimum Roster</td>
</tr>
<tr>
<td>1</td>
<td>73</td>
<td>6,500</td>
</tr>
<tr>
<td>2</td>
<td>116</td>
<td>10,813</td>
</tr>
<tr>
<td>3</td>
<td>342</td>
<td>26,130</td>
</tr>
</tbody>
</table>

162.
Thus, there was a total saving of 2,719 minutes in 43,511 minutes or 6 per cent of penalty payments. In addition to achieving this direct saving the time required for roster preparation was reduced considerably.

The construction of a fortnightly rotating duty roster was again treated as an assignment problem. In this case, however, the complexity is such that a time optimum, i.e., minimum cost, roster cannot be guaranteed, but a near optimal result is obtained.

The basic award conditions applying in this particular case were:-

The ordinary hours of duty must not exceed 40 hours each week to be worked on not more than five days which may include weekdays, Saturdays or Sundays.

Ordinary hours worked in excess of 40 in each week must be paid for at a penalty rate.

Duty worked in excess of 8½ hours on any schedule has already been treated as overtime in Phases I and II and is not considered in the assessment of the ordinary hours worked in the week.

Employees must be rostered off on two clear days in each week.

Schedules worked on consecutive days must be separated by a break of not less than 10 hours.

As far as practicable, an employee will be rostered off on alternate Sundays.

In addition, to improve general efficiency and in the interests of good staff relations the following constraints were included:-
In any fortnightly period, an employee will be rostered for one week of early finishing schedules and one week of late finishing schedules.

Where practicable, employees are rostered to work straight or broken schedules according to preference.

In any weekly period, an employee is allocated as many identical schedules or as many schedules with similar starting times as is practicable.

Saturday and Sunday schedules, which attract penalty payments, are distributed throughout the roster as evenly as possible.

Employees should be rostered off on as many consecutive days as is practicable.

All Sundays in early finishing weeks will be rostered as days off.

The first step in the optimisation process was to set up a day off pattern with the maximum number of four and three days off groups. This formed the framework into which the shifts were allocated.

The duty roster is initially set up by placing the schedules for each day in the order of increasing finishing times and then, if necessary, re-ordering these to obtain a break of at least ten hours between schedules on consecutive days. In the initial placement or in any subsequent re-ordering, no schedules are placed in a location which has been reserved as "day off".

After the initial placement of schedules, the list of schedules for each day, in turn, is re-ordered for allocation to each line of the duty roster so that, in order of priority, the following is achieved:

1. feasibility is maintained.
2. maximum decrease in overtime is obtained.
3. maximum increase in the total number of identical schedules in a week's work is obtained.
maximum increase is obtained in the total similar starting time score, which is defined for each week thus: each pair of schedules scores two if their sign on times are within twenty minutes of each other, one if the difference between the sign on times is between 20 and 60 minutes, and zero otherwise.

This process of re-ordering schedules is treated as an assignment problem with inadmissible squares. The process is executed twice after which no further worthwhile improvement is obtained.

Examples of the improvements achieved are given in the following table:

<table>
<thead>
<tr>
<th>Roster</th>
<th>Overtime</th>
<th>Undertime</th>
<th>No. of matching pairs of shifts</th>
<th>No. of similar starting times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>2,754</td>
<td>1,001</td>
<td>588</td>
<td>1,196</td>
</tr>
<tr>
<td>Optimal</td>
<td>2,369</td>
<td>616</td>
<td>1,028</td>
<td>1,586</td>
</tr>
</tbody>
</table>

Surprisingly, however, the client regarded the cost savings as being of somewhat lesser value than the intangible benefits to the organisation. His assessment of the benefits was:

"From the management point of view the whole project of having consultants work with our own staff in automating the preparation of duty rosters for traffic crews has proved to be very worthwhile and has yielded the following benefits:

1. Top management now has a means of effective control over traffic costs which was not previously available, in that:
   Rosters are now being prepared on a minimum-cost basis.
   The mechanised procedure allows a quick evaluation to be made of the effect of
changes or proposed changes in industrial working conditions.

More accurate estimates of the effect of service adjustments, extensions of service or the introduction of new services can be obtained.

2. The time required to prepare new duty rosters has been reduced from eight weeks to three weeks, enabling more frequent reviews of both timetables and rosters to be made, with consequential financial benefits.

3. The roster staff have been required to define clearly the problems they are attempting to solve and to detail in writing the procedures used, thereby clarifying these matters in their minds and giving them a more critical outlook on their work.

4. The reduction in roster preparation time has encouraged flexibility in approach and facilities experimentation to test new ideas to achieve better results.

5. There are benefits to traffic crews in the form of better arrangement of work schedules".

CASE STUDY 3: PROJECT SCHEDULING

In this case a Scheduling Model was developed to schedule a large number of projects over a given period to obtain maximum benefit from limited funds and other resources.

The first step is to analyse each project to establish the benefit to the community, the cost, the place and type of project, the time required for construction and pre-construction activities, the earliest possible starting date and the year of need.
The model then sorts projects into a priority order based upon benefit/cost ratio or some similar parameter. The model has been designed to accept also priority lists upon judgement or social ratings. The total project costs are met from a number of alternative funds using prescribed rules for the amounts to be drawn from each fund. A typical set of rules (called a "Fund Transform Table") is shown below:

<table>
<thead>
<tr>
<th></th>
<th>Col. 1</th>
<th></th>
<th>Col. 2</th>
<th></th>
<th>Col. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fund No.</td>
<td>2301</td>
<td>%</td>
<td>2302</td>
<td>%</td>
<td>301</td>
</tr>
<tr>
<td>Row A</td>
<td>50</td>
<td></td>
<td>25</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Row B</td>
<td>2304</td>
<td></td>
<td>301</td>
<td></td>
<td>312</td>
</tr>
<tr>
<td>Row C</td>
<td>301</td>
<td></td>
<td>312</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Row D</td>
<td>312</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The first row nominates up to four funds and the proportions of the cost are to be met from each fund. The funds in Rows B, C and D are back up funds which may be called upon if the main funds are exhausted.

Resource requirements for each year of each project are calculated from the annual cost and the project type.

An attempt is made to schedule each project as early as possible. The funds and resources available are then tested for sufficiency. If there are insufficient funds or resources in any category in any year, the project is delayed as many years as is necessary and the funds and resources are again tested for sufficiency. When, after any necessary delays, both funds and resources are found to be sufficient, the amounts of each fund and resource needed in each year by the project are deducted from the balances of the relevant funds and resources, and the project is said to be 'scheduled'. If a project is delayed so that it is commenced but not completed within the given time period, the amounts of funds and resources which are
needed to complete the project are recorded. If due to lack of funds or resources, a project cannot be commenced within the given period it is said to be unscheduled, and the amounts of funds and resources needed by the project are recorded.

A facility is available to enable the user to omit either the fund or resource sufficiency check and so to determine the funds required to fully utilise all available resources and vice versa.

Some generalised examples of the application of the principles incorporated in the Scheduling Model will serve to illustrate its usefulness. Generally, as all the inputs to the Model may be varied, it is possible to assess the implications of the policy decisions corresponding to various sets of input data.

For any given distribution of funds and resources, together with the rules for their use, the Model will determine the number and type of projects to be constructed, project timing, benefits and unused funds and resources, for a given list of projects in priority sequence. By manipulation of priorities or constraints on the use of funds (say in certain areas or certain type of projects) or resources, the implications or equivalent policy decisions can be assessed. By eliminating some or all constraints within the Model the "free" situation can be compared with other cases. The sensitivity of results to selected priority ratings can be assessed by varying the priority measure and re-examining the results for significant differences. The implications of committing selected projects for construction can be assessed by assigning over-riding absolute priority. Any shortage of resources (say engineers' time) in a particular geographical area or in a particular field (say bridge design) can be assessed by omitting the resources check option in the Model, or
alternatively shortfalls in funds can be assessed by omitting the fund check option.

In addition, as previously described, facility is provided for reports to be produced by the Model at regular and "critical" stages. By reference to the date and summaries in these reports it is possible to identify reasons behind the final results for any run of the Model and this information provided a basis for adjustments to input data so that a close to optimum result can be achieved by an iterative process.

In this particular instance it is impossible to pinpoint any direct financial gain to the client. However, by using the Model he was able to schedule a large number of projects strictly on a basis of priority to maximise his economic returns for any given fund level and to make realistic estimates of finish dates and resource requirements which could not have been achieved without the Model. In fact he was able to present a clear, logical work sequence and so remove much of the personal, intuitive judgement common in such cases. When alternative schedules were suggested he was able to re-calculate the cost and resource requirements quickly and easily so that final decisions could be taken with all parties agreed that they represented the best available solution.

5. CASE STUDY 4: REGIONAL FREIGHT MOVEMENT

A good example of a very large operations research study is the recent case of the analysis of freight movement within a region and overseas via a number of ports. The objective of the study was to analyse the costs of and demands for transport service, the establishment of the future demand and the most effective way of using all components in the system to provide the lowest level of transport costs commensurate with an adequate level of service to the community.
The terms of reference required that an examination be made of the likely economic and demographic development of the region over the period to 1985. This included an assessment of economic activity and the associated import and export of materials and the results were combined with origin-destination data of present goods movements to form the basis of loading for the future transport system.

A special computer systems model has been formulated to test a number of alternative transport systems. In addition to road/rail alternatives these include the testing of alternative port development or constraints policies, leading to either a continuation of the present multiple port system or to the development of a centralised port concept.

The inputs of the Model include either costs or charges for each transport mode and commodity type where applicable, origin and destination of goods movements, annual tonnages to be moved and data on seasonal fluctuations.

The output gives the annual loading by commodity type on each link of the rail, road or shipping system, loadings at the ports and the total transport system charge or cost for each alternative considered.

In addition, technical and organisational studies have been made of the railway system and major ports in the region. Information has been collated from a road inventory to provide a basis for determining road system deficiencies which may occur as a result of changed patterns of movement during the period under study.

Thus, the regional authority has been provided with a detailed analysis of the costs and benefits of a number of alternative development concepts and is in a position to choose between them with a high degree of confidence in the correctness of their judgement. An incorrect decision
at this time could cost hundreds of millions of dollars between now and 1985 and so the development of a model to test alternative schemes is of inestimable value to the authority. In fact, in this case, the difference between choice of the best policy and a laissez faire approach represented an annual saving of several million dollars.

6. SUMMARY

In summary, then, I would repeat that operations research covers such a wide spectrum of techniques and applications that we must tailor the analysis to meet the particular problem and the money and time available for the study. The returns from small jobs are often more easily measured than those from large projects, but in the latter case the overall savings can be tremendous.
Figure 1. Cost as a function of claim strategy

ACCIDENT COST ABOVE WHICH A CLAIM IS MADE

TOTAL COST
PREMIUMS
ACCIDENT COST TO COMPANY
A DISTRIBUTION PROBLEM IN THE PETROLEUM INDUSTRY.

G. GREGORY AND K.A. JONES

I don't know how many study groups have worked on distribution problems in the petroleum industry over the years; it must run well into three figures, and OR methods have, of course, been applied and with a good measure of success. And yet, so far as I can see, the important subject of retail petrol selling has not benefited nearly as much as it might from the OR approach.

The starting point in this type of study, or in any OR study for that matter, is as complete an understanding of the operation as it is possible to acquire. In this case it meant discussion with men experienced in this work. Most of them had experience extending over very many years and in many different localities. There was an extensive literature in the form of textbooks, reports, manuals and the like, and, by no means least, the financial records that told the story in figures of past successes and failures. Then followed close personal observation of service stations over the whole hours of operation, from opening to closing, and over successive days. This of course must be done with the help and understanding of at least some of the operators and their staffs, and requires a certain amount of tact. I think it is inevitable that many things will be observed that have no direct bearing on the study and which are best ignored. In due course there emerges a fair
idea of what significant features can be expressed in numbers and recorded from observation, and the study can proceed. I consider that this introductory phase is vital and make no apology for stressing what may seem obvious to many. This process cannot be presented here but it is possible to describe briefly the economic organisation of service stations as a group and the contribution which consumer research makes, and this will convey an understanding of what we are studying.

Service stations exhibit a marked degree of uniformity compared with retail establishments in other industries, whether measured in terms of cost, turnover, number of employees or the physical size and appearance of premises.

Since stations' markets are in the vehicles that pass their driveways, location at an intersection with access to two or more traffic lanes usually confers a tactical advantage over the competitor with access to one lane only.

Petrol sales could, for the most part, account for something like one half of the profit. The balance will come from the sale of goods and services of various kinds, oil, accessories and so on. It tends to be confined to goods and services that can be sold without lengthy use of large areas of high priced land.

The most important fixed cost is usually the financing of high priced land.

The most important single item of variable cost is labour. Casual labour for selling petrol at peak periods is not always readily available, partly from cost and partly because of cash control considerations.
Labour is not completely mobile as between the petrol pumps and the other activities which go to make up the balanced profit.

Although income is geared to petrol sales, the time actually occupied in selling petrol tends to be concentrated into peak periods and takes up quite a small proportion of the total hours worked.

Many service stations operate close to break even point financially. Having adjusted to one level of operation, they do not readily adjust to a higher one without a fairly good idea of what that level is and firm expectations that it will be reached. It is possible for a service station to stabilize its operation well below its economic potential and continue thus indefinitely.

The distribution of arrival intervals between successive customers is such that when stations approach the limit of their capacity to serve petrol – without an unacceptable wait for service – petrol selling facilities are in use for quite a small fraction of the total working hours. The organisation could be regarded as a working compromise taking into account the cost of providing petrol trading capacity that can be used for a small proportion of operating hours and the loss of profit if business goes to competitors better able to take advantage of peak trading conditions, all with due regard to balanced profit. That is to say, the profit than can be earned by supplying customers who normally call for fuel with tyres, batteries, oil, mechanical advice and service and so on.
Very often the basic problem facing a study group, whether at an existing station or at a site where a station is planned, will be to determine as accurately as possible the maximum petrol sales that can be obtained at the site given reasonably efficient management.

The results of consumer research can be summed up briefly for present purposes. Petrol buyers have preferences, which can be influenced by advertising and sales promotional activities. These preferences can be measured and expressed as numerical ratings by the well developed methods of consumer research. The product purchased is in fact a combination of the petrol itself, the personal attributes of the dealer and the features of his establishment. Thus a survey will give a variety of reasons for purchasing a brand, or at a certain station. These reasons could be the superior quality of the petrol as a fuel, the personality of the dealer, his reputation for fair dealing or mechanical competence, or it may just be the convenience of the station's location. Buyers do not always go to the same station, nor do all buyers at the same station have the same scale of preferences.

Convenience is by far the most common reason given for buying a brand or patronising a station, and it seems to mean that the motorist is able to satisfy his petrol or related needs with a minimum of trouble and without departing far from a normal line of travel.

Consumer survey methods provide very good measures of the relative appeal, in the customers' minds, of the various factors influencing sales. They are necessary and important, but even when a searching series of questions
is cross-referenced and carefully checked for strong and consistent elements, the survey does not, of itself, measure in useful terms, the factors dominating actual purchasing.

The logical method of probing further into the problem is by close observation of the actions of buyers and sellers, with the object of finding ways of expressing significant features in useful numerical measures.

There appear to be two avenues of approach.

The first is an analysis of vehicles calling at a number of competing stations for fuel, expressed as a percentage of the total number of vehicles passing their driveways. In doing this, the records should be kept so that later on, both traffic and buyers can be classified in detail if desired. The direction of travel, time of day, origin and destination of a particular part of the traffic, type of vehicle, day of the week, male or female driver, and almost certain to be matters of importance.

With suitable breakdowns, it will be possible to make due allowance for the varying density of the different types of traffic passing each service station and arrive at percentages of traffic which will serve as a first estimate of sales performance.

As a matter of interest, a theoretical standard for comparison can be derived by considering a closed circuit with a number of service stations along its length. This approximates a system where cars leave their garages at the beginning of the day, traverse a route around a city or whatever it may be, and return again later on, passing a number of service stations on the way, at any of which they could buy fuel if they wished to. If all service
stations along the route had an equal attraction and business is equally distributed, the following relationship will hold:

\[ P = \frac{1}{fn} \]

where

- \( P \) = Percentage of vehicles in passing traffic calling for fuel at a service station.
- \( n \) = number of service stations per mile of route.
- \( f \) = vehicles' mileage between calls for fuel, divided by 100

\( f \) can be closely approximated by consumer research; around Melbourne it could be estimated at between 1 and 1.25.

In practice it will never be practicable to fully analyse the origin and destination of traffic, but reasonably close estimates can be made from observation without too much trouble. The main constituent is the flow of traffic between residential and commercial or industrial areas which follows well-defined patterns and is strongly peaked. For many reasons the commercial sector is not likely to be troublesome.

It is inevitable that some degree of approximation will enter into the work, usually because of the limitations imposed by time and expense, and a balance is reached between time or cost, and the expected practical value of greater accuracy in detail. The theoretical figure obtained from the above formula gives a useful standard to compare with figures obtained from actual observation, and in practice close agreement has been found.

With percentage sales figures for a number of stations, and consumer research ratings of the customer appeal of the various factors, a multiple correlation analysis yields measures of their apparent relative effect on sales.
I use the word "apparent" at this point because, with traffic and selling so strongly peaked, it is necessary to devise some means of taking into account the situation that arises when some stations start to have difficulty in coping with the business available in the very busy periods when most petrol is sold. This must occur, if preferences expressed by buyers take effect in the market place and there must be a point where the inconvenience of entering an already busy station overcomes the attraction of preferred factors.

Even so, some fundamental points will now emerge which will simplify proceedings at a later stage when it becomes desirable to concentrate on one or two important aspects and measure them with as much accuracy as is possible.

The first important point to emerge, I think, is that customer response to any factor follows a law of diminishing returns: that is, there is a fairly broad area of what might be called "fair, average quality" where differences are not of great importance, but the reaction to sub-standard performance below this band is much more drastic than to higher achievement above it.

There would be little doubt also, I think, that factors of dealer attraction and station characteristics generally out-weigh quality of petrol as a fuel.

The limitations imposed by serving capacity can be seen in the lines of cars drawn to cut price stations by price difference of the order of 5c. to 7½c. per gallon in Melbourne.

The second useful measure derived from observation pertains to the arrival intervals and service times of vehicles calling at stations for fuel. These approximate the form shown in the diagram and in combination measure the probability that one or more service points will be occupied when a vehicle arrives for service. We have already seen the way in which traffic
has very marked peak characteristics and that petrol buying tends to be concentrated into well marked peak periods. Here, we have a measure, derived from observation, of the stations' ability to cope with the business available. It might be appropriate to note here that motorists generally follow much the same route from day to day, or at least, pass the same service stations many times. Although they may not shop around extensively among the many stations available, they do come to know many of the characteristics of the stations at which they are likely to purchase and can avoid a station if experience or observation lead to a belief that service will be slow.

Here, then, is a fairly precise measure of a powerful overall force which tends to distribute business, within limits, more or less equally among available service stations when trading becomes busy. A certain amount of judgement and experience are needed to spread observation over the decisive periods of time, although this is not difficult in practise. There is, for example, no point at all in timing arrivals and service times with accuracy during mid-morning or mid-afternoon on a quiet day when arrivals may be spaced twenty minutes or more apart. Because it is a characteristic of nearly all service stations in and around Melbourne, that petrol selling capacity is used for a small proportion of total operating hours, the probability of wait for service at decisive times is a measure, and the only one available, to gauge the relative strength of limited trading capacity in diverting business. It can also be another means of estimating the sales effect of selling factors, in that willingness to accept the inconvenience of wait for service, when
present, can measure the sales worth of an attraction, in diverting business from competitors. An illustration easily observed is the behaviour of buyers at stations offering substantial price cuts or free give-aways on an uneconomic scale.

Arrival intervals and service times conform to mathematical distributions well enough for all practical purposes, but even so, the calculations are mathematically difficult. There is no great difficulty in programming a digital computer to do the work, but my preference would be for a portable analog machine constructed according to the diagram shown and which operates in the way shown.

The advantage of a machine of this type is that it gives on-the-job flexibility, in adapting to the characteristics of different stations at different times and in predicting the results of possible changes.

The problem now enters the stage where three essential measures are available for a number of competing stations.

1. Percentage of buyers drawn from available traffic suitably classified.
2. Consumer research ratings of the customer appeal of the various factors.
3. Distribution of arrival intervals and service times.

One method of procedure at this point will be a determination of the limiting effect of capacity to sell from item 3. It might be as well to mention that a limitation of this reason may not be easily cured by extra labour at critical times or even by installing an extra petrol pump. In studying one large station we found it necessary to construct a scale model of the station and use small cars to simulate the operation as business
increased beyond a certain point. You may find that it is necessary to re-design the whole layout to provide increased capacity at peak periods.

Having determined the limiting effect of capacity to serve, it is probably that a correlation calculation will be the best means of determining the variation of sales with the strength of buyers' preferences for the various factors entering into station operation, i.e. clean appearance, courteous service and so forth.

It should usually be sufficient to express the effect of increased demand on a station's capacity to serve as a probability that one or more service points will be occupied on arrival of a customer. However, there is inherent in the changes observed in arrival, and possibly service patterns, as the load increases, the baulking of customers who normally would have purchased but have been diverted by unwillingness to wait. The rate can be calculated from observed data, although the mathematical work is difficult. A baulking rate would be of the greatest importance, and might well be the decisive factor in the study of a particular station and is therefore well worth pursuing.

I do not intend to go into this calculation in detail here, but will now assume that with a working understanding of the relative value of the important factors we are approaching the problem of assessing the petrol sales potential of a site at which no station as yet exists. The problem really comes down to one of assessing the differences that will result when an additional station is added to the series of stations along a stretch of traffic. The trading percentages of the existing stations, or as many
of them as need by, will be known as well as their important features. In so far as methodology is concerned, there is really nothing to add to what has gone before.

I have been too long at this job to expect that a first study of this type will measure, with great precision and beyond all doubt, the precise number of sales gallons attracted by a small change in customer preference for one factor, although I am sure that with experience even this can be expected. What can be achieved, however, is firm statistical evidence defining areas that are sensitive or insensitive to changes in buyers' preferences along with useful estimates of their sales significance in the existing trading conditions. It could support a hypothesis arising from a trading problem, as for instance, whether a service station is operating at full economic potential, and if not, what should be done about it. These are important problems.

In conclusion there are one or two points arising from earlier discussion on the economic organisation of service stations that could be mentioned.

It was noted that high land cost generally responsible for the most important item in fixed costs, and this fact points to break-even analysis as a starting point should financial stringency be suspected as a probable reason for sub-standard performance.

It will be recalled also that labour is usually by far the largest item of variable expense, and this suggests an activity study if unfavourable trading tendencies are disclosed. This is not likely to get far without an effective sampling plan. Dr. Jowett, when he was Reader in Statistics at Melbourne University, gave me a plan which has worked well
for me and which I pass on. It is not theoretically watertight, but the differences are not of practical importance. I hope no one will expect a full explanation, but the fundamentals are as follows:

1. Prepare a schedule of 60 instants, in order of time, choosing 6 at random in each 2 minute interval.
2. Allocate two of these instants to each of the subjects whom we may designate A., B. and C.
3. Mark the activity by a code letter: i.e.
   W - working
   Y - talking
   T - thinking
   M - missing.
4. Observe the subject at the scheduled instants and insert an 0 or 1 to indicate the results of observation.
5. Calculate percentage of time subject is engaged in each activity and determine probable limits of accuracy which are:

\[ M \pm 2 \sqrt{\text{Mean semi-squared difference}} \]
COST EFFECTIVENESS CRITERIA
IN OPEN PIT MINE DESIGN

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INTRODUCTION

General procedures are presented for the design of open pit mines. The design process is seen as an iterative application of procedures each of which may be an optimum solution for the given input conditions.

Preliminary stages discussed include co-ordination of drilling information and calculation of ore block composition. This is followed by calculation of block economic value and determination of economic pit limits. Final stages include detailed determination of mining sequence and calculation of final economics.

The use of computer techniques to carry out directed design procedures and automated graphical presentation of results eases the heavy burden of repeated calculations and drafting. This allows an overall optimum solution to be achieved with minimal human resources.

Effectiveness of design is measured by comparison of design alternatives.

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PRESENTATION OF DRILLING INFORMATION

Accurate co-ordination of drill hole traverse paths and location of drill core sample information is the first step towards definition of the ore body and its composition.

Clear graphical representation of this sample data as sectionally projected views next follows in order to ensure sufficient drilling has been carried out, and to plan additional drilling should this be necessary. Definition of natural spatial composition trends and structural features is facilitated by presentation of composition information as histograms drawn perpendicular to the drill hole centre lines. Special computer programs are now used to automate the drafting operations required for graphical presentation of drilling information, these systems make possible the highly detailed mapping of all collected drill core information with extreme accuracy at a cost which is considerably lower than that for manual drafting.

DETERMINATION OF ORE BODY COMPOSITION

The customary approach to definition of ore body composition and calculation of ore reserves has been to compute average grades for selected regions of drill core, and then to assign these grade values to polygonal regions of the ore body.

In the case of open pit mine design, and to facilitate solution of the design problem by computer, the region under consideration is more readily regarded as divided into smaller adjacent rectangular prismatic blocks. A computer program is used to identify all regions of drill core lying within each block, and to compute block composition on the basis of enclosed core sample values and their associated sample lengths. Where there is insufficient drill core within a particular block to confidently define its composition, the frequency distribution of adjacent grade information may be used to assist grade prediction.

Definition of the composition of blocks not intersected by drilling is usually performed by careful consideration of observed structural features and grade trends. Interpolation of these block grades is carried out along observable trend directions where these exist, or by assuming continuity of the
ore distribution where these trends are not markedly defined. It is essential that sufficient drilling has been carried out to confirm continuity or otherwise of ore distribution and to ensure interpolated values lie within acceptable confidence limits.

Confirmation of the effectiveness of block grade definition is obtained by plotting bench by bench plan views of original drilling information and computed block grades. All stages described above may be carried out by computer provided adequate guidance information is supplied to ensure the task is properly carried out. Computer drawn contour maps may be produced for each bench to assist confirmation and visualisation of trends both within given benches, and through successive benches in a vertical direction.

**BLOCK ECONOMIC VALUE ASSIGNMENT**

In order to make possible an optimum pit design and financial evaluation, the economic value of each block must be computed.

Block values are first calculated assuming they will pass through the mill and the extracted saleable materials sold.

Income from any ore block is calculated from the block dimensions, its original composition, expected mill recovery and expected unit costs of the resulting extracted saleable material.

Costs associated with any ore block are computed from its block dimensions and

- unit breakage costs.
- unit haulage costs (function of distance and height hauled).
- unit milling and treatment costs.
- unit transportation costs.
- unit overheads associated with the operation under investigation.

The block economic value (BEV) is computed for each block by subtracting costs from income.
If the BEV of any block is greater than zero, it is assumed to be ore and to be processed by the mill. It is otherwise assumed to be waste and the BEV is recalculated as a negative value, this being the total of waste and haulage costs.

A clear picture of BEV's may be obtained by contouring these values for all benches. This immediately highlights overburden locations and forms an excellent basis for review when production is under way.

DETERMINATION OF OPTIMUM PIT OUTLINE

A feasible pit must be such that the slope of the pit face does not exceed a safe angle. Access to the pit and sufficient room to manoeuvre equipment within the pit are additional requirements to be considered.

The optimum pit outline is computed from consideration of the BEV for each block together with the location of given blocks within the pit space. Three types of situations may arise as follows:

(i) Blocks with a positive BEV which are exposed at any stage and require no overburden removal at that stage prior to their removal. Any block of this type is considered as mineable ore and may be removed.

(ii) Blocks with a positive BEV which are not exposed at any stage, but which are next in line for removal. The BEV of a block of this type must be added to the BEVs of associated overburden blocks. If the total BEV for the group is positive, the block under consideration together with its associated overburden blocks may be removed.

The above block evaluation process is continued until there is no block group remaining which has a positive BEV. The outline of the optimum pit for the specified economic conditions is thus defined, and may be mapped in plan and sectional views for access design.
COMPUTATION OF ORE RESERVES AND REVIEW OF BLOCK ECONOMIC VALUES

Once an optimum pit outline has been determined for a given cost structure and mill throughput rate, ore reserve tonnages and grades and waste/ore ratios may be calculated. Overall financial detail follows from addition of ore BEV's or by the use of block compositions and locations.

At this stage, review of cost estimates, mill throughput rates, etc. is most likely to be required. Successive redefinition of these basic parameters, recalculations of BEV's and re-determination of the optimum pit outline may be performed to converge on an overall general optimum solution, and to investigate the effects of metal price variations, mill recoveries and so forth.

Additional refinements in BEV calculation may be used by considering depth as an approximate measure of the date of mining of individual blocks. Using this, BEV's may be re-computed as present values, these then being used for definition of the pit outline.

EFFECTIVENESS OF DESIGN OF PIT OUTLINE

Given a set of blocks of defined composition, together with the associated income and cost structure, any alternative pit design may be financially evaluated by selection of blocks for a particular design.

Experience has shown that the use of a correctly structured computer procedure for design of the optimum pit outline has a high probability of being superior to a manually produced design. Up to 30 percent increase in profitability may be achieved where the ore body is disseminated, has considerable variation in composition and has considerable overburden.

The ability to refine a design and to quickly modify a design in the light of new information is a powerful argument in favour of the computer approach.

189.
DETERMINATION OF MINING SEQUENCE

The sequence of mining is primarily governed by:
- the process of successively removing exposed blocks.
- the need of access for removal of material.
- the maintenance of minimum slope conditions on pit sides at all times to ensure slope stability.

Within the above constraints, there are innumerable block mining sequence combinations possible. Determination of an optimum mining sequence consists of two stages:

(i) Definition of the block mining sequence which satisfies the above constraints, and also gives a maximum cumulative cash flow at every point in time until all blocks within the optimum pit outline have been mined.

This process is carried out by the use of dynamic programming techniques.

(ii) Modification of the maximum cash flow mining sequence defined in (i) above by imposition of penalties resulting from unnecessary equipment relocation, unacceptable variations in mill head grade, and so forth as may apply to the particular environment.

This process is performed by simulation of the actual mining process and altering the mining sequence by considering the factors operating at each point.

REVIEW OF TOTAL DESIGN

During the process of mining sequence definition, much greater detail of operations becomes apparent. Modifications to mining rates, mining costs, etc. are most likely to be required. Should these change significantly, it may be necessary to recalculate BEVs' redefine the optimum pit outline and redefine the mining sequence.

At this stage, a complete production plan is available with its associated cash flow picture. This provides the expected date of
removal of each block of material and this enables the present value of the basic BEV to be calculated and assigned as the working value for the BEV. Detailed refinement of the design on the basis of a present value criterion is thus possible at this stage by repeating the design process from the BEV calculation stage.

If additional drilling information comes to hand which significantly alters or extends the definition of block composition, it may be necessary to repeat the design process from the block composition definition stage.

**EFFECTIVENESS OF TOTAL DESIGN**

As may be seen from the foregoing discussion, the design process is necessarily iterative, although optimum solutions may be directly found for a given operating framework. The effectiveness of the design process is made apparent by comparison of preliminary with final solutions, these being generally compared on an economic basis.

While design effectiveness is dependent on the use of correct procedures in the design process, the final result is built on the foundation of basic information and its accuracy. Some of the potential sources of data error are mentioned below:

- Inaccuracy of drill hole surveying and spacial location of core sample data may affect calculation of ore block composition and thus all succeeding steps.

- Intensity of drilling and consistency of grade trends must be considered when determining the dimensions of the basic ore blocks.

- Metal price forecasts may be incorrect. Study of the effect of various metal prices on the design is an essential part of the design process.

- Grade interpolation may not be extremely accurate. Study of the effects of grade variation from plan should be considered. The effects of ore dilution during selective mining should be allowed for in the design.

- Treatment plant performance may differ from that proposed. Will this have any significant affect on target performance?
- Should inflation be allowed for in estimation of costs, or do contract figures apply?

Review the whole design problem indicates that the structure of problem solution is very important, as objectives are attained for the stated problem. Accuracy of end results will be a function of accuracy of primary data and performance of each design procedure. The design process should terminate when the results of successive designs are consistent to a degree reasonably expected from the data available.
I. INTRODUCTION

This paper outlines the development and implementation of a project involving the use of Operations Research techniques in "de-bottlenecking" a production facility. It illustrates the use of two concepts sometimes ignored in such projects namely, that major benefits accrue from the use of a team involving individuals differing in technical experience and background and, secondly, that the extensive use of computing facilities need not always be an essential part of such projects.

The project arose through differing estimates of the effective capacity of the milling operation of The Mount Lyell Mining and Railway Company Limited's copper mine at Queenstown in South-Western Tasmania, leading to a Company executive suggesting that the use of simulation techniques might help resolve the matter. This, in turn, resulted in the General Manager of the Company securing the part-time assistance of the Operations Research Consultant from the Management Services Division of Consolidated Gold Fields Australia Limited.

II. THE OVERALL TASK

a) Project Definition and Personal Involvement

The objectives of the project were to identify the effective capacity of the milling operation, to locate any bottlenecks preventing the attainment of that capacity and, where it could be justified, to eliminate or reduce the effect of those bottlenecks. From the outset, it was resolved to work through a small team which was established without disrupting the normal production and maintenance staff. This approach demanded extremely close and effective liaison between the team and the Mill Production and Maintenance Superintendents.
The time and effort that was put into maintaining this liaison more than paid off later in the ready acceptance of early recommendations and in the ease with which the team was able to break up as their activities were absorbed into the normal operation of the mine. In determining the composition of the team, prime importance was attached to selecting members who were highly motivated, determined and able. The final composition, excluding the Consultant, was an Executive Engineer, a Research Metallurgist and a Project Officer (Mechanical Engineer). The time involvement of the individual team members fluctuated widely, but at all times the project retained top priority for them.

The overall Mount Lyell operation can be summarised as comprising various mining operations feeding ore, through ore passes, to a rail-haulage network which delivers the ore direct to the crushing plant. The crushed (fine) ore is fed to storage bins of relatively small capacity after which it is ground and the mineral content extracted by a flotation process. The concentrates are then filtered and stored.

Initial discussions identified a strong presumption that the major limitation to production lay in the crushing operation and that further, if this were true, the sequential nature of that process indicated that little benefit would result from simulating the operation. However, it was also abundantly clear that, if the main restrictions to production did occur in this area, there was real advantage to be gained from the construction of a logical model of the process followed by the collection of the appropriate data and the close and critical analysis of that data. In effect, a simulation model and its data, but no computer runs. The prime point of such an analysis was, of course, to identify areas where changes could be instituted profitably and this, in turn, was only worthwhile if a follow-up procedure was established to ensure that the expected gains were in fact attained.

b) The Payoff

The above steps were those that were ultimately applied with direct and measured success. The measure of the
success has been a sustained increase of 8% in throughput relative to a reference period of 12 weeks. Prior to commencement of the project, it was acknowledged that this reference period represented a time of high production.

III. THE MILL

a) "Model" Logic and Data

Adopting the criteria mentioned above, all available plant records covering milling, grinding and flotation for the reference period were assembled. A pilot week was then selected and, working from the relevant flow-sheets with cross-reference back to the available operating data, the plant was broken down into logical elements. Obvious major subdivisions were crushing, grinding and flotation. Factors affecting this split were the availability of fine ore storage; the practice of enforcing a regular weekly down-shift for crushing plant maintenance, without normally extending this to the grinding and flotation operations, and the serial nature of the crushing operation compared to the availability of parallel paths in the other two operations. Based on this logical dissection, and using the plant records for the pilot week, it was possible to build up a set of parameters which adequately described the performance of the individual elements of the plant and which, when combined arithmetically, described accurately the overall performance. When satisfied that the logical breakdown was sound and that reasonable data was obtainable, the data for the full 12 week period was tackled.

At this point it is worth emphasising that the guiding principle in deciding which data should be collected was - "if one were building a detailed simulation model, what data would be required". This was the data that was collected, although no effort was made to prepare a computer program of the model.

Events were defined to be either external or internal to the unit being considered. Once a particular type of lost time had been defined as internal to one
piece of equipment, it was automatically external to all other equipment and hence eliminated from their analyses. In this way the sum of the internal losses for all units in, for example, the crushing plant could be added to give the total lost time in the crushing plant due to events within that plant. All other lost times were external to it and therefore analysed elsewhere.

Using this approach, it was possible to be confident that, should lost time be eliminated in one area - say at a particular crusher - it would result in a true increase in crushing plant capacity and would not be eroded due to related events elsewhere within the crushing section. Of course, to convert this increase in capacity into production required that facilities external to the crushing plant should be able to both keep up the supply of material and take advantage of the increased production. In this way, the Rail Haulage System and the Grinding Plants were external to the Crushing Plant and so on. Within each area, statistics of times off-line were gathered and collated by duration and cause. Distribution curves for operating rates while on-line were equally important.

b) Analysis, Action and Follow-Up

From this data it was obvious that the dominant causes of lost production lay within the crushing section. Moreover, due to the way in which the data had been collected, it was immediately possible to quantify the gains that could be expected both in terms of improved times on-line and effective rates while on-line. These tabulations formed the basic reference document for much of the work that followed and have provided the framework for a regular reporting system.

Having identified the areas of major potential improvement, attention was then directed to ensuring that what had been recorded did in fact accord with what really went on in the plant.
Two members of the team immediately acquired shift operating experience and various operating staff and executives placed themselves on call so that particular operating problems could be observed and appreciated at first-hand.

At this stage, a list of de-bottlenecking activities was compiled, ranging over such varied items as -

- improved lighting in some areas
- reorganisation of shift supervisors and operators
- changed maintenance schedules and techniques
- changed materials of construction or methods of fabrication of some elements, e.g. screens
- plant modifications
- modified operating techniques

In compiling this initial list, and in the subsequent additions to it, strict attention was paid to ensuring that the effects of any proposed change were related back to the basic analysis and that the specific factor which would be affected was identified. In this way, a number of proposals which might otherwise have been accepted were rejected on the grounds that either the gains could not be explicitly identified, or they had been already claimed elsewhere. Additionally, this provided a means of consistently rating the potential gains or savings of each proposal and against which the cost was compared before a decision was taken to proceed.

Once this initial list had been compiled, brief plant development meetings were organised and attended by the team and appropriate operating, maintenance and engineering staff. At these meetings the various proposals were finally evaluated and scheduled for implementation depending upon the benefits and degree of difficulty involved. Again, the time and effort spent in ensuring that good communications existed between all staff involved had its payoff in the rapidity with which agreement was reached and action taken.
IV. THE RAIL HAULAGE OPERATION

a) The Problem and the Need for a Model

In the course of this work on the crushing plant, it became obvious that some additional thought should be given to the ability of the rail-haulage system to meet the extra demands which would result from any increase in mill throughput. To a large extent, the same approach was used. Staff involvement and good communications were again the point on which action hinged. Definitions were established, data obtained, and members of the team became involved with the physical rail-haulage operation for a short period. Retaining the internal-external basis of lost time analysis again gave clear measure of the times lost for various reasons, and established that the losses attributable to mining were quite minor. It was, therefore, legitimate to concentrate on the rail-haulage system rather than on the mining operation itself.

At this point, similarity with the earlier part of the project ceased. As the rail-haulage operation was a batch process using a restricted number of trains feeding from several ore-passes, the overall effect of changing one or more of the performance indices was by no means obvious. Each train consisted of two locomotives and a number of ore trucks. Under these circumstances, it was decided to take the further step of using a simulation model.

Analysis of the data collected on the rail-haulage operation, and discussion between the relevant executives led to agreement that the most likely avenue for improvement lay in dramatically reducing the number of ore trucks per train. This action was expected to improve locomotive availability to the stage where one existing long train could be replaced by two short ones. The question to be resolved was whether the resultant increase in traffic would allow increased tonnage to be hauled, or merely produce another bottleneck. To resolve this problem, a simulation model was required.
b) **Use of the Model**

Due to the remoteness of the location and the desire to obtain an answer in the shortest possible time, it was decided to perform the simulation by hand. In spite of the tedious nature of this task, it had the very real advantage that no "outsiders" were involved in this, the Company’s first attempt to "run" a simulation model. Company staff collected the data, devised the model, performed the calculations, analysed the results and decided to implement the short train operation - the decision being implemented some three weeks after starting work on the model.

For this model, parameters describing equipment availability on a "normal" and a "bad" day were defined. Using standard loading and run-time distributions, single and dual train operations were simulated for a "normal" day and dual train operations for a "bad" day. Results obtained from the single train on a "normal" day confirmed the validity of the method of calculation. The two remaining cases adequately demonstrated the increase in throughput that was attainable by the use of shorter trains and the greatly enhanced flexibility of operation that also resulted.

c) **The Payoff**

It is worth emphasising that, before the above simulations were performed, it was evident that smaller trains would improve mechanical reliability. However, the results of the simulation runs convinced management that not only could the system cope with the added traffic, but that the overall haulage capacity would increase and sensitivity to many typical delays would be reduced.

The success of this simulation, tedious as it was, has resulted in The Mount Lyell Mining and Railway Company Limited adopting the use of simulation models as a means of evaluating the future development of their rail-haulage operations. Needless to say, this work employs computer methods since the models involved are larger and involve more complex problems and few people would seriously suggest the performance of hand simulation calculations as a suitable means of regularly utilising the time of skilled staff.
However, it is relevant to note that this latter development owes much to the availability of a computer package allowing mine planning engineers to design and run their own models without spending significant time in learning to programme a computer.

V. CONCLUSION

This paper has attempted to illustrate the approach in one project involving the use of some of the techniques of Operations Research. It has shown that a sound appreciation of the methods used in constructing and using simulation models can be a potent tool for the analysis of some operating problems, either with or without the construction of a formal computer model. It has also identified the value of a team providing varied skills and the benefits resulting from the maintenance of good communications in important areas. In this way and by keeping the relevant Operations Research techniques in their correct perspective - as very useful tools - Management was able to get on with the job of making better decisions based on better information and reaping the resultant benefits.

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