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# A DECISION SUPPORT SYSTEM FOR CORPORATE PLANNING IN THE NEW ZEALAND DAIRY INDUSTRY

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ABSTRACT

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Index Terms

Decisions; Support; Systems; Planning; Optimization; Heuristics; Network programming; Fixed Costs; Travelling salesman; Distances; Computer graphics.

A Decision Support System (DSS) is described, the prime objective of which is to aid in the location of new investments in a multi-site, multi-product dairy processing company. A network program model is described which optimises the collection of milk from farm groups (netcells) and the allocation of the milk to a range of final products and byproducts through consideration of product prices, process costs and transport costs. Constraints include process capacities, overtime capacities, and final product demands. Site dependant product yields are considered through use of an iteration procedure surrounding the network model. This procedure updates estimates of the mean company yield used to set upper and lower arc constraints in the product demand phase of the network model.

Milk tanker collection distances are estimated by an expected travelling salesman distance method in conjunction with accurately measured netcell to factory 'bridging distances' and an inter-factory 'diversion' network of road distances.

To cope with daily fixed cost charges, a heuristic procedure employing cost relaxations and a number of pre-solution feasibility tests is used.

Seasonally varying factors (milk supply, product yield and farms visited per tanker trip) are accommodated by solving the network model for the average day in each month for twelve months, then summing the results multiplied by the number of production days in each month.

Implementation as a DSS was facilitated through use of an interactive computer system incorporating computer-generated graphic displays.

Applications of the DSS to location planning, industry rationalization and other corporate planning activities are described.

Recommendations on the use of the model to identify the feasible set of candidates for location studies are made, and methods for identifying the appropriate timing of investments are considered.

# TYPOGRAPHICAL CORRECTIONS

| Page | Line | Correction |
|---|---|---|
| 16 | 17 | modelling |
| 20 | 13 | severely |
| 28 | 18 | paramaterised |
| 32 | 8 | incorporates |
| 43 | 16, 18 | manhattan |
| 49 | 7 | mixed-integer |
| 59 | 5 | constraints |
| 59(c) | 4th to last | $l_{ij}$ |
| 59(c) | 2nd to last | $c_{ij}$ |
| 65(a) | 8 | $Y_j$ |
| 88(a) | 1 | Evaluation of d as used in sort criterion |
| 99 | 6 | are (instead of "were") |
| 118 | 17 | model |
| 154 | 2nd to last | fixed-charge |
| 154 | last line | 1968 |
| 155 | 10 | fixed-charge |
| 166 | 14 | $\varepsilon$ |

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I wish to acknowledge gratefully the dedicated supervision of Dr Brian R. Smith (Victoria University) and Dr Kevin R. Hall (Department of Scientific and Industrial Research, DSIR). The guidance and inspiration of Professor G.A. Vignaux and Dr John R. Troughton were also highly valued.

The DSIR is thanked for its financial support and provision of computing facilities. Office and library facilities were provided by Victoria University and the Ministry of Agriculture and Fisheries. In particular, the services provided by Margaret Turner (Word Processing), Jill Fowke (Equation typing) and Margaret Phillips (Interloan publication requests) were especially appreciated.

The commitment of time and effort by the New Zealand Co-operative Dairy Co. Ltd. was particularly encouraging. Special note must be taken of the enthusiasm, persistence and dedicated application of that organisation's 'staff analyst', Ms Vicky Forgie without whom this thesis would have described a DSS in name alone.

P.J. Mellalieu

# DECLARATION

The theoretical developments described in this thesis are my own work, as was the design, programming and implementation of the SUPGEN, ETSCALC, NETPLAN, DCF/COMPARE and associated graphic computer programs. The NETAG program was designed by me, but programmed by Stephen P. White. The Out-of-Kilter network program algorithm was provided by Kevin R. Hall. The programs for the standard business-type graphs were provided by Tektronix Inc, through MacLean Information Technology. Data for the NZCDC and South Auckland and Bay of Plenty NETPLAN models was jointly collected and set up by Vicky Forgie, the Barr Burgess consultants and myself.

# ABBREVIATIONS AND SPECIAL TERMS

| | |
|---|---|
| ALLOPT | Fixed plus variable cost optimization |
| AMF | Anhydrous milk fat |
| AUTOFIXIN | Automatic inclusion of factories from previous solution with non-zero flow. |
| BBA | Barr-Burgess Associates Ltd. |
| BMP | Buttermilk powder |
| COG | Centre of gravity |
| DCF | Discounted Cash Flow |
| DP | Dynamic Program |
| DSS | Decision Support System |
| ETS | Expected travelling salesman |
| ETSCALC | Expected travelling salesman distance calculator. |
| LP | Linear Program |
| MAF | Ministry of Agriculture and Fisheries |
| NETAG | Netplan annual result aggregation |
| NETPLAN | Network program planning |
| NPW, NPV | Net Present Worth, Value |
| NZCDC | New Zealand Co-operative Dairy Company |
| NZDB | New Zealand Dairy Board |
| SUPGEN | Supply data generation |
| VAROPT | Variable cost optimization |
| wt/vol | weight per volume |

# CHAPTER 1

# OBJECTIVES AND OUTLINE

This study was concerned with researching the application of Decision Support Systems for corporate planning. A particular concern has been to integrate the traditional mathematical modelling techniques of operational research with the emergent technologies of interactive graphics computing using the Decision Support System framework.

The design, development and implementation of a Decision Support System (DSS) for a large New Zealand dairy products manufacturing company is described. The principal purpose of the DSS was to improve decisions relating to the size, type and location of investments in processing capacity. The need for these investments as well as other requirements for the DSS are described in Chapter 2. Background information on the dairy company, and the technical constraints and relationships under which the company operates are also discussed.

The objectives of the DSS approach are reviewed in Chapter 3 and the literature is evaluated with particular reference to location, transportation, and production planning studies. The chapter concludes by specifying in greater detail the mathematical modeling and system implementation features to be adopted.

The mathematical and logical aspects of the model are detailed in Chapters 4 and 5. Performance and validation experience are provided, supplemented by Appendix 1. Contributions to the fields of applied network optimization, expected lengths of travelling salesman tours and fixed cost minimization are explained in these chapters.

Chapter 6 describes the technical (hardware and software) features which were used to "judiciously couple" the computer-based model to the decision maker's skill and judgement. Particular attention is given to the value of the interactive and graphics-oriented capabilities of the configuration. Implementation and applications of the complete DSS within the company are given in Chapter 7, whilst Chapter 8 describes an application to industry-wide restructuring.

The contributions to both mathematical modelling practice and field of Decision Support Systems are summarized in Chapter 9. In addition, further research possibilities are indicated.

# CHAPTER 2

# INVESTMENT AND PLANNING REQUIREMENTS IN THE NEW ZEALAND DAIRY PROCESSING INDUSTRY

## 2.1 Introduction

The large and diverse New Zealand dairy industry requires substantial investment in new and replacement processing plant over the next 10 years. The New Zealand Co-operative Dairy Co Ltd is the largest company in the industry and typifies many of the problems faced by the industry.

To help in planning the company's plant investments a model of their supply, transport and processing activities is required. The general features and design requirements of such a model are described.

## 2.2 Sectors of the Dairy Industry

The New Zealand Dairy Industry comprises four major sectors.

The farm sector produced 320,000 tonnes of milkfat in the 1980/81 season, from 16,000 farms.

The processing sector is made up of co-operatively owned dairy companies. This sector is concerned with the collection and processing of 91% of the milk into dairy products such as cheese, butter, caseins and milkpowders.

The third sector is the New Zealand Dairy Board which both exports and sells locally the processed products. Exports accounted for

$1,065 million in 1980/81. (88% of the total production.) In addition the Dairy Board determines the marketing strategy of the industry and co-ordinates dairy products manufacture through a system of annually-reviewed price contracts with each of the dairy processing companies. The Board also has some influence on the capital investment programmes carried out by the dairy companies.

The town milk sector is concerned with the collection, bottling and distribution of fresh milk for household consumption. This sector accounts for most of the remaining 9% of milk produced.

This study is concerned primarily with the processing sector, which over the next 10 years, plans to invest some $700 million in upgrading and replacing processing facilities throughout the country. These substantial investments are required in response to three factors: the increase in milk production; the need to upgrade or replace plant which is cost inefficient, or fails to meet ever tightening quality and hygiene standards; the need to diversify the product mix in order to achieve higher and more stable market returns.

## 2.3 Importance of Location and Other Factors

The optimal location of investments in plant is particularly important in the dairy industry mainly because transport costs are a major ongoing cost component. This is due to the fact that milk is collected daily in refrigerated vehicles from each farm.

Dairy processing equipment has a long economic life usually in excess of 15 years. Buildings and utilities, such as steam generating plant have even longer economic lives, and this is a second reason for ensuring a good location is chosen.

Consequently, in planning for new investments it is necessary to consider the following factors:

(a) the timing of the investment

(b) changes in total milk supply and the quantity of milk supplied from different parts of the study region

(c) changes in the product mix and demand requirements

(d) changes in product prices

Additionally there are various technical constraints and relationships which influence the planning exercise. These are:

(a) All milk supplied must be processed on the day of supply otherwise final product quality will be severaly degraded.

(b) The quantity of milk supplied per day varies in a skewed mountain shaped form over the 12 monthly production season (Figure 2.1).

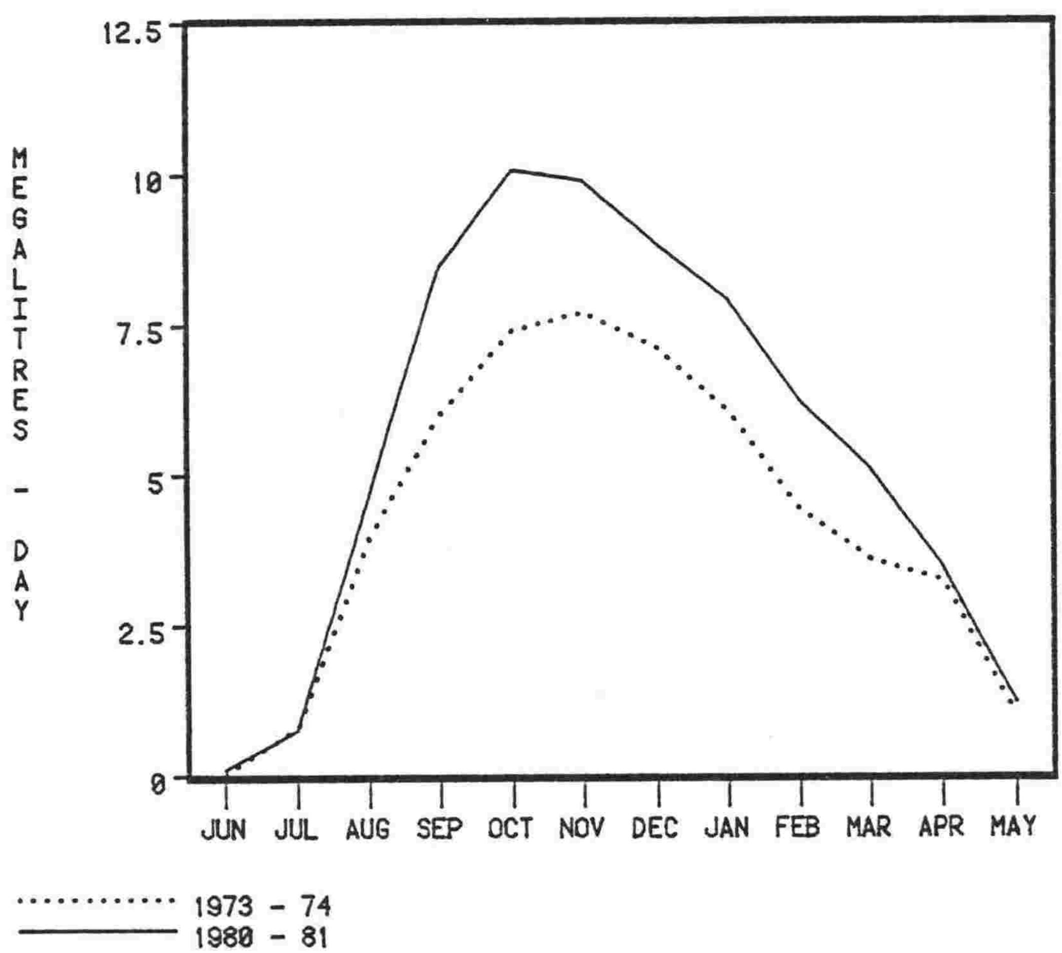
(c) The milk composition varies from month to month, and from area to area, and this effects the yields of final product.

(d) In addition to the major products derived from the milk, various byproducts are available which must be disposed of or processed into useful forms (Figure 2.2).

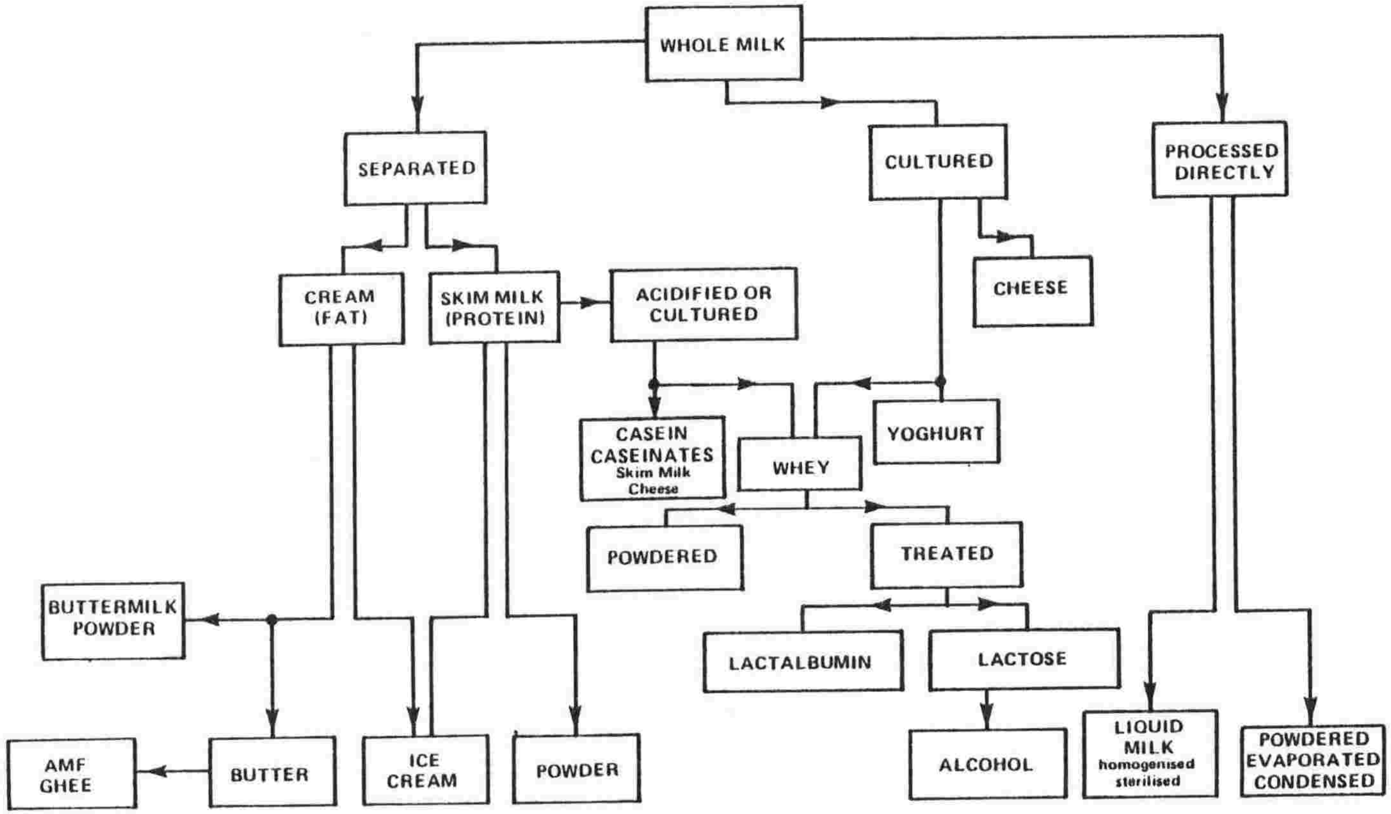
(e) The efficient utilisation of milk tankers requires that collection of milk be carried out in a complex way in that a

20 (a)

Fig. 2.1 NZCDC DAILY MILK SUPPLY




Source: NZCDC Ltd




Source: Ministry of Agriculture & Fisheries

Fig. 2.2 Milk Products and byproducts

20 (b)

number of farm suppliers are visited on one tanker trip. In addition the number of farms visited per trip varies throughout the season, in association with the seasonal changes in farm production.

(f) Factory operating costs are particularly non-linear, and comprise annual start up (maintenance) costs, fixed costs, daily start up/close down costs, shift costs, overtime costs and variable processing costs.

(g) Factories and processes within factories have finite maximum capacities related to the process rate, number of shifts worked, and overtime available.

Another issue is the need to allow decision makers to take account of less quantifiable aspects. For example, the dairy industry historically has been rural based not only from the viewpoint of the supply of raw material, but also from a location and labour supply viewpoint. More recently, there have been trends towards urbanisation of the processing sector in both a locational and technological sense. This has a serious impact on rural services, rural housing, worker management relationships and the "quality of life" generally.

The huge number of data items relating to supplies, costs, demands and capacities, combined with the large number of interrelationships gives rise to the need for a modelling approach to identify the optimal locations for new plant investments. In addition, the overall complexity of the model demands that effective methods are needed to explain the model's method of approach and to convince the user of the correctness of output results.

The planning environment is constantly changing. In particular, predictions relating to product demand and milk supply will change as the company actually moves through the planning horizon. Consequently, investment plans need to be re-evaluated in the light of the company's actual experience and revised predictions. This suggests the need for a model which is flexible in its use, and able to be used by the company well after the model designer has departed.

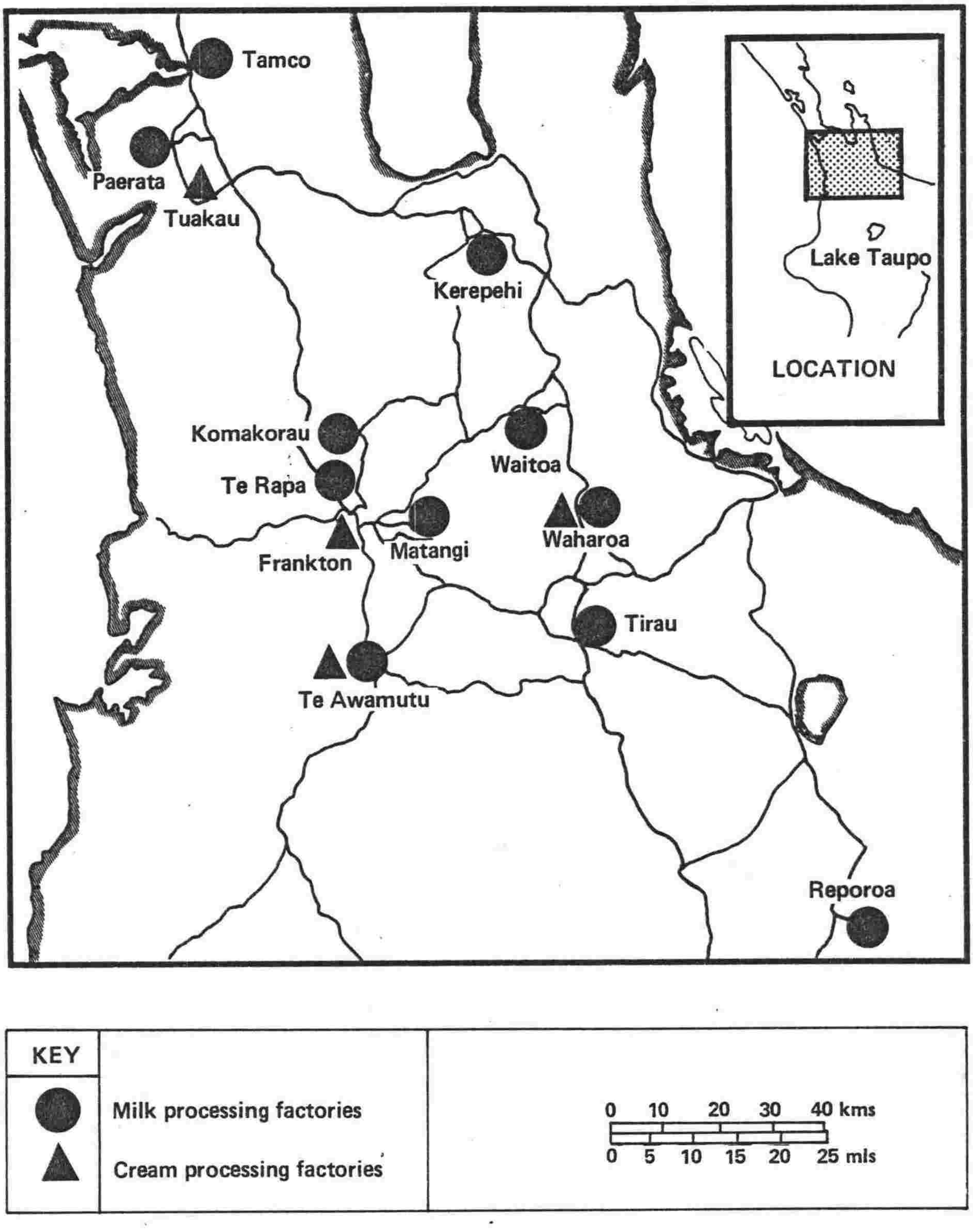
## 2.4 The New Zealand Co-operative Dairy Company Limited

The New Zealand Co-operative Dairy Co Ltd (NZCDC) is the largest dairy processing company in New Zealand. It collects milk from 4500 farms scattered over an area of 10 000 $km^2$ (Figure 2.3). Collection is carried out by 300 refrigerated road tankers. Fifteen factories throughout the area produce virtually the whole range of dairy products plus byproducts. The factories range in size from those processing a few hundred kilolitres of milk per day into a single product to multi-process factories processing up to 2000 kilolitres/day.

The NZCDC faces an investment of $200 million over the next 10 years for the reasons described in Section 2.2. This investment translates into the need for a new or replacement dairy factory every two to three years. Consequently the company expressed considerable interest in the development of an investment planning

**Fig 2.3:**

***NZ Cooperative Dairy Co Ltd factory locations and supply area (1981)***



model. They further indicated the desirability of using the model for other planning applications, such as analysing the effects of unplanned plant closure due to events such as powder explosions.

## 2.5 Conclusions

To assist in the planning of capital investments in the dairy industry, a model is required which

(a) comprehensively takes account of the many technical relationships

(b) conveniently manages the large quantities of data consumed and produced

(c) produces output results in a form helpful to the user

(d) can be used effectively by a non specialist user

(e) carries out the analysis in a fast and cost effective manner

(f) has a design logic which readily convinces the user of its correctness

(g) is flexible enough to accommodate considerable changes in data and planning requirements.

# CHAPTER 3

# APPROACHES TO THE BUILDING OF A LOCATION PLANNING MODEL

## 3.1 Introduction

This chapter examines the literature pertaining to techniques for modelling systems in a manner which meet the requirements specified in chapter 2.

The literature and techniques are evaluated on the basis of mathematical suitability, computational speed, flexibility, and adaptability. General comments on the modelling process and the non-mathematical aspects of a model are also considered, particularly with regard to the way in which the model will be used by the company's decision makers. The review concludes with the choice of techniques which have the most relevance for construction of the required model.

In addition to reviewing the subject areas of location theory and investment timing, previous dairy industry studies and some aspects of corporate planning models are examined.

## 3.2 General Aspects of Model Design

General features relevant to the design of computer-based models are discussed in this section. The relevance of Decision Support Systems which combine computer and human decision making components are described. This is followed with an examination of the role of model evaluation as a guide to model design.

Scott-Morton and Huff (1980) in their review of the impact of computers on planning and decision making discuss the recent development of Decision Support Systems (DSS). They give the objective of Decision Support Systems as:

"to improve a given decision maker's ability to deal with semi-structured problems by judiciously coupling human skill and judgement with the data manipulation and numerical power of computer systems, but not to replace the decision maker altogether with a computer system that would make the decision for him."

DSS is compared with the more traditional computing applications which are concerned with well-structured efficiency-oriented applications. These they called Management Information Systems (MIS), examples of which are payroll and inventory control systems.

They continued by pointing out that DSS aided problem solving is essentially interactive and is dependent on much of its power and usefulness on a capability for dialogue between a manager and the computer. Reviewing corporate simulation models, they found that managers gained a deeper insight into the operation being modelled, enabling them to see the organisation from new perspectives and so helping them develop new strategies.

DSS applications have hitherto been relatively few in number because of limits imposed by algorithmic and computer speed, and the need for more extensive programming compared with batch oriented systems (for example interactive dialog, crash proofing, automatic job control). Wagner (1981) stated that only 1% of data processing personnel were involved in DSS. As recently as 1982, Vazsonyi in his review suggested that future DSS applications would incorporate powerful mathematical models (such as LP, goal programming, Markov theory) in contrast to the more ad hoc modelling provided by, for example, the IBM Interactive Financial Planning System. He noted the novelty of embedding an LP into a DSS as was achieved by Stott and Douglas (1981) in their ocean transportation scheduler.

Other significant developments in DSS have included the work of Alter (1980) who investigated current practice and proposed a taxonomy for the description of DSS. A review of practical and theoretical aspects of DSS was carried out by the International Institute of Applied Systems Analysis (IIASA), with the proceedings edited by Fick and Sprague (1980). Proceedings of an earlier conference were edited by Carlson (1977).

Plant location is usually considered to be a well-structured problem to which well-defined methods can be applied in order to determine optimal investment proposals. Such methods are discussed later. In practical situations, however, the plant location problem is not such a well-structured problem. Many factors relevant to the decision only become apparent as the decision maker becomes deeply involved in his analysis. This was borne out by early discussions with planning executives at NZCDC.

They indicated that following the presentation to top-management of one set of results, often an entirely new analysis would be requested. Such an analysis might include changes in factory capacity levels, or product mix, or a series of "what if" questions relating to new perceptions of the planning problem.

Factors such as the need to locate a factory in an area in order to pre-empt competitors from doing likewise, or the need to support rural redevelopment are less quantifiable factors which the decision makers also wished to evaluate. Consequently, the DSS approach was found to have much relevance for this work.

We turn now to issues of model evaluation as a guide to model design. Gass (1977) asks the question "on what basis should a decision maker rely on and use the outputs of (complex) decision models?" He considers the concepts of model verification and model validation, and proposes a set of guidelines for accomplishing the evaluation of a complex model. He suggests that model development should take account of these guidelines in order to "increase the validity of the model and its acceptance by the decision makers".

Gass emphasises that a model includes not only mathematical and logical constructs but also the appropriateness of data; model assumptions; the role of the model in the decision making process; program specifications and model maintenance. This suggests the need for a balanced approach to model building rather than an overemphasis on the mathematical aspect. This is confirmed by Scott-Morton et al, who after reviewing a number of studies on the success and failure of computer aided planning, concluded:

"It seems that what leads to success is not so much the level of sophistication of the management science models used, nor the speed with which the computer executes the program, nor the grand scale of the development project itself. What appears to matter is the provision of computer support for a small clearly identified and reasonably well understood component of the overall planning process; the simplicity and relatively low cost of the related computer systems development; and the extent to which managers actually used the system and felt they had improved their decisions by so doing."

Finally, Gass states that

"In general, the decision maker must be given the opportunity to explore the use of the model in order to become familiar with its predictions and to examine the relationships and assumptions implied by the model."

It will be described in chapters 4, 5 and 6 how the model developed in this study conforms with the modelling qualities outlined above through use of a network modelling approach; paramatised data structures; simple interactive dialog; user-oriented reports; and graphic display of results.

## 3.3 Planning and Location Studies in the Dairy Industry

This section reviews the modelling of dairy industry problems in a number of countries. A range of relevant applications are discussed which include optimal location of dairy factories in Ireland, transport minimising models in the US, a production planning model in New Zealand, a "spatial efficiency" model in the South Auckland dairying region, and the use of computer based milk-tanker scheduling models for various factories in New Zealand.

O'Dwyer carried out a series of highly detailed studies of the Irish dairy industry. Use was made of a budgetary approach to determine the extent of economies of scale in the manufacture of skim milk powder (O'Dwyer 1968, III). Next, structural changes in milk supply were examined using Markov chain analysis (O'Dwyer, 1968, I). He compared various methods of collecting milk and cream from farms and creameries (O'Dwyer, 1968, II) and then finally Stollsteimer's (1963) heuristic method was used to determine the number, location and size of dairy manufacturing plants.

This last study is severely limited in its application to the current work in that it modeled a greatly simplified situation. For example one identical process cost function was used for all factory sites. Albeit, the function did encompass a diminishing average cost of production. Just two products were made: skim milk powder and butter, although this was justified on the basis that 80% of milk was actually processed into these products in his study region. These products are made in a fixed proportion to each other (butter from the cream fraction whilst powder is made from the remaining skim milk fraction). Thus there was no scope in the model for specifying product mixes (refer to Figure 2.2). No account was taken of the seasonal variation in milk supply or the changes in supply over the years: only total annual production for one year was considered.

The techniques comparing alternative methods of collecting milk and cream are of historical interest only. In New Zealand generally all milk is collected by road tanker, whilst O'Dwyer was comparing the delivery by farmers of milk in churns to a creamery with a "multican" system in which a truck from the creamery visited farmers on a more efficient collection route. At the same time, tanker collection was being introduced in Ireland, and it was necessary to indicate which of the three collection systems would be most cost efficient in the long term.

Siebert, Boles and Revzan (1968) developed an LP transportation model for the purpose of investigating the movement of milk supplies within California. They were concerned with proposals to change the state's method of payment to farmers from a contract-based system to one employing price incentives to encourage transport of milk from supply to demand areas. These price incentives were obtained from the least cost transportation solution. Such a concern with price incentives is not of relevance to the current study, because in New Zealand dairy companies are co-operatively owned by the dairy farmers, and all farmers receive an identical payout from their company (though payouts differ among companies). Secondly the current study requires consideration of more factors than transportation. However, of interest is the regression analysis they carried out to determine transport costs as a function of load, distance and other factors; this is discussed in Section 3.4.

Kloth and Blakley (1971) used separable programming to minimise assembly, processing and distribution costs for the US home milk industry (i.e. not the dairy products industry with which we are concerned). The IBM Separable Programming System was used to cope with an exponentially decreasing per unit processing cost. Market concentration constraints were also employed - that is, limits were set on the maximum proportion of each market which could be supplied by one firm.

The problem to which the model was applied concerned the use of transport subsidies and a single point base price system in the US. The results of the model showed that with the existing system, excessive transport of milk was encouraged, and some process plants were encouraged to locate in sub-optimal locations near the point at which the base price was calculated. ("Sub-optimal" means with respect to models in which transport cost allowances were reduced and/or market share restrictions relaxed.)

The limitations of this model are:

(a) No account was taken of seasonal variation in milk supply, or consumption. This may have been because the model was concerned with liquid milk rather than milk products manufacture.

(b) Considerable aggregation of data (although necessary to cope with the whole of the US).

(c) The cost of collection of milk from farms to the (fictional) major supply point was ignored. This is a crucial factor in the management of a multi-factory dairy company. This aggregation aspect is discussed later in Section 3.4.

The use of market share constraints is not relevant to the co-operative New Zealand dairy processing industry. Product distribution costs are less relevant also, as will be shown in Chapter 4.

Benseman (1976) constructed a production planning model for the NZCDC using Burroughs' TEMPO Linear Programming and GAMMA matrix generator and report-writer software. The model represents processing of products and by-products and incoporates raw material blending which is required for specialised products such as baby foods. Seasonally-varying product yields are incorporated. The objective function maximises net variable revenue, which includes selling prices, variable process costs, milk collection and by-product diversion costs. Neither fixed costs nor non-linear processing costs are included due to lack of data though the former costs may be readily incorporated using the TEMPO branch and bound facilities.

The transport aspect of the model is limited, with the milk supply being considered to originate in seven transport centres, resulting in a total of 70 transport variables. The model optimises on a per day basis only: there is no time stage optimisation over a whole year. In order to achieve total annual production requirements, LP constraints are manually altered throughout the planning periods to ensure the required production. (There are 36 10-day planning periods in the year.) Being a production planning model, the number and capacities of factories are well known prior to running the LP, in comparison with the models of O'Dwyer described above.

The model produces a number of management-oriented reports, and continues to be well used by the company for production planning. The model does not permit interactive use due to the large time required for matrix generation, LP solution and report writing.

Clark (1979) investigated the "efficiency with which a particular spatial system involving a number of plants can be integrated through space". The area of his study was the South Auckland dairying region, including NZCDC. The model considered inter-factory transhipment of cream (the most valuable milk by-product) using the standard transportation method.

First considering NZCDC alone it was found that reductions of 7.2% in distance travelled could be achieved. This was based on known total annual supplies and demands for cream, and therefore ignored the seasonal variation in cream production. This was subsequently considered by solving the transportation problem for 12 individual months. The distance saving dropped to 4.4%. With regard to the whole region the results indicated a potential saving of 9.5% if all company boundaries on cream ownership were ignored.

Clark's work was concerned with analysing the existing situation in the region, with the object of determining the benefits of a restructuring of corporate relationships. Conclusions from the study were that such a restructuring was unlikely to occur primarily because the benefits of restructuring would be unevenly divided.

Nevertheless as Chapter 8 will show, the possibility of restructuring was subsequently contemplated by the region's dairy companies, but only after far more detailed analysis undertaken with the model developed in this work.

The small difference between the actual and theoretically optimal cream transport for NZCDC is probably due to the Company's use of Benseman's LP model, already described. If so then this indicates that different optima could be being prescribed by the two models. One reason for this is that Benseman's model included cream processing costs and final product selling prices which vary from plant to plant due to quality variations. This factor would tend to increase transportation so that the maximum return was obtained from the cream. On the other hand, Clark modelled transport to a more detailed level than Benseman, thereby achieving a more finely-tuned cream distribution. Finally, the company may have chosen to deviate from the optimal plan for other reasons.

As well as pointing to the potential benefits of corporate restructuring, Clark's work highlights the need to dissaggregate annual commodity flows into smaller time periods to cope with the varying milk supply. The fact that actual and theoretical transport plans were closely aligned points towards the acceptability of using an optimisation technique in the current study. The major limitation of Clark's work is that it fails to deal with the more massive milk collection and milk processing component of the company.

## Milk Tanker Scheduling

Scheduling of the daily tanker collection runs is a time consuming task because the schedules have to be redone every few days due to the changing milk supply per farm. In New Zealand the scheduling task has hitherto been done manually, in order to take account of highly specific details (such as bridge weight limits and tight turning circles at some farms restricting truck size). Recently however, computer based scheduling systems have been tested with some success (Foulds, Tham and O'Brien, 1977, Roper, 1981). These have been based around the well known Clarke-Wright (1964) heuristic algorithm. A feature of Roper's method was the incorporation of some of the decision rules that the manual schedulers used. This aided the acceptance of the technique by the staff. The advantage of the technique has been the speed with which new schedules are prepared. Actual improvements to existing schedules have been relatively small (but significant in terms of cost saving) of the order of 5% or less in distance travelled.

One limitation of the technique is that it deals with collection to one factory only, hence the need for some other method of determining the overall allocation of milk between factories.

## 3.4 Approaches to solving the location problem

The location problem has been examined from many points of view. This section begins by reviewing the infinite set and feasible set approaches to the general problem, and discusses some of the solution techniques used. Optimal and heuristic solution techniques are also discussed, as is the relevance of transportation modelling to the wider problem. The influence of distance representation and data aggregation on the choice of approach is considered, and a technique to estimate distances based on "expected travelling salesman" distances is described.

Other aspects considered are the relationship between expected and actual distances, transport costs and distances, and the impact of raw material and final product transport aspects on problem formulation.

Infinite set and feasible set approaches

Eilon, Watson-Gandy and Christofides (1971) in reviewing the literature distinguished between two main approaches to the depot location problem: the "infinite set" and the "feasible set" approaches. Other writers (Krarup and Pruzan, 1980) have used the terms "planar" and "network".

The infinite set approach suggests that a site may be located anywhere in the region of interest. Consequently it is possible that an optimal site may be indicated for an unsuitable location, such as in a swamp, lake or mountain range. Alternative solutions are possible in multi-site selection problems, and transport costs must be a monotonic (increasing) function of distance.

Eilon et al made significant advances on the work of Miehle (1958) and Cooper (1964) and their "Model 6" is of particular relevance in solving the infinite set problem.

The model takes account of:

(a) district-dependent warehousing costs with fixed costs and returns to scale

(b) district-dependent trunking costs between a factory and the warehouses

(c) local distribution costs from warehouses to customers.

A heuristic technique is used to determine the location, number and size of depots which minimize total costs.

A useful development is that the warehouses can be prevented from being located in an infeasible area by assigning a very high trunking cost to the area.

Eilon et al suggest the method could be applied to other cost functions. It may be possible therefore to invert the direction of flow in their model and consider a model which takes account of:

(a) district dependent "warehouse" processing costs with fixed costs and returns to scale

(b) local collection costs from farms to "warehouses"

and ignores trunking costs.

With respect to the dairy company planning problem, the limitations of Model 6, or a variation thereof are:

(a) failure to incorporate district-dependent collection (distribution) costs,

(b) failure to cope with multi-product, multi-process factories (warehouses)

(c) failure to cope with by-product distribution

(d) failure to cope with the time-varying nature of the raw material supply, both within the season, and from year to year

(e) failure to take account of existing facilities.

The prospect of modifying the model therefore appears formidable.

The prime requirement of the feasible set approach is the determination of a finite set of sites which are known to be feasible, and for which cost data is available (Eilon et al, 1971). Costs can be incorporated which are related to specific geographic locations, and transport costs do not need to be a monotonic function of distance. The major limitation of the finite set approach is that the set of feasible sites may not include the optimal site.

There is a continuing debate about which approach (feasible set or infinite set) is better. Eilon et al suggest that it is a simple matter to exclude mountains, lakes and other indesirable locations from the feasible set, but there still remains a vast geographic area to be considered. Consequently, a large feasible set is available which generates huge data and computing requirements.

Proponents of the feasible set approach argue that the approximate nature of the cost functions used in the infinite set approach are a significant drawback and hence their preference for the more precise information obtained from the feasible set approach.

Solution techniques for the feasible set approach

Techniques which have been used to solve finite set location problems include the standard linear programming, mixed integer programming and separable programming methods already mentioned in section 3.3. Network programming techniques (NP) using the out-of-kilter (Ford and Fulkerson, 1962) and Primal Simplex optimising algorithms for capacitated networks are increasingly being used due to their fast solution time compared with LP methods (Glover, Karney & Klingman, 1973, Bradley, Brown & Graves, 1977). Although less flexible than LP techniques in terms of the model formulations which can be analysed, their high solution speed permits NP formulation to be embodied into a more general optimisation or heuristic framework (Sa, 1968, Florian & Robillard, 1971, Kennington, 1976, Nauss, 1978, Barr, Glover & Klingman, 1979). A second feature of networks is their pictorial nature which aids in understanding the formulation.

Heuristic techniques generally embody "add", "drop" and "swap" phases, (some times called "bump" and "shift"). In an "add" phase a location which is currently set at a zero capacity is brought into the set of possible locations and the total cost evaluated. The location is kept in the set if the increase in process costs is overwhelmed by a decrease in transport costs. Otherwise, the location is kept out of the set of locations. Such a method was developed by Kuehn and Hamburger (1963). A "drop" phase aims to eliminate non-zero capacity locations thereby increasing transport costs but with a greater reduction in processing costs (Feldman, Lehrer and Ray, 1966).

Sa (1968) employed both phases and included a "swap" phase which carries out a one-for-one exchange between a zero capacity location and a non-zero capacity location. Various heuristics are used to select candidates for adding, dropping or swapping (Logan and King, 1964, Stammer 1971, Rodgers, 1974). The disadvantages of such techniques is that the global optimum is sometimes not achieved. Another disadvantage is that some of the heuristics apply to particular types of problems and tend to lack applicability to real planning problems. The major advantage of a heuristic approach is that a good near-optimal solution can be obtained quickly in comparison with optimisation techniques.

Techniques applied to the solution of the classical transportation problem with fixed charges sometimes have a wider application to location problems. Balinski (1961) developed a relaxation which obtains a better solution than if fixed costs are ignored, and which indicates bounds for the true optimal solution, (though the optimal solution was not obtained). This relaxation was used subsequently by Barr, Glover and Klingman (1979) in developing an optimal technique for solving large-scale fixed charge transportation problems. A combination of branch-and-bound procedures and a Network Programming (NP) algorithm is used with various branching criteria being evaluated. Although the best method employed Driebeek's (1966) "dual pivot look ahead penalty" in association with a Primal Simplex NP, a simpler, but reasonably efficient separation criterion used the deviation between actual flow-related costs and the Balinski relaxed cost. This latter method does not require the use of a Primal Simplex algorithm.

Florian and Robillard (1971) proposed a more specialised method for dealing with a capacitated network with concave costs, finite supplies and demands. The approach employed branch-and-bound, implicit enumeration of a set of external flows in the network, and use of bounding conditions based on Balinski's relaxation. The method was claimed to be optimal but was never implemented on a computer or tested.

Gray (1968) also developed a method of optimally solving the classic problem by eliminating many of the sub-problems through calculation of bound criteria on the total fixed cost allowed in the optimal solution, and comparing this bound with the fixed cost component of the sub-problems about to be solved. This technique can be generalised to certain types of capacitated transhipment models, as discussed in Chapter 5.

Erlenkotter (1978) developed a fast optimal method of solving the uncapacitated facility location problem with fixed costs employing a Lagrangian relaxation, branch-and-bound and LP dual formulation. Nauss (1978) developed a method for solving the capacitated problem using similar techniques (but with an NP). Both approaches are not readily generalised to the more complex planning problems faced by the dairy industry.

Distance, transport costs and data aggregation effects

Krarup and Pruzan (1980) focused on the influence of distance on modelling location problems with particular reference to 'computational tractability' and on the quality of solutions obtained. They indicated that to the best of their knowledge no systematic analysis had been done comparing the "network" and "planar" approaches.

The concept of data "aggregation" was dealt with in some detail and this has particular relevance to the current study. They noted that "it is not operationally meaningful to attempt to accurately measure the distance between a potential object location and a client and that therefore it may be acceptable to replace direct measurement (e.g. road kilometres) by some kind of distance metric". For example, in household rubbish collection, a number of houses are visited on one trip in which case, a "there and back" distance is not appropriate, and they note that experimental evidence (Goodchild, 1978) "indicates that the effect of aggregation errors on the solutions to median problems, both within a planar and network context, are substantial and that solutions based upon aggregation data are open to extensive manipulation, dependent upon the aggregation procedures employed". Various aggregation procedures are outlined and strong recommendation was given to the use of a "hybrid planar-network" formulation to take advantage of the positive features of both finite and infinite set approaches. The approach involves

(a) aggregation of client demand into suitable areas

(b) assuming the demand emanates from a single point within the aggregation area

(c) calculating directly the distances between aggregate points and other points (e.g. depot locations) through use of an appropriate distance metric (discussed later)

(d) use of an NP algorithm to solve the problem.

The advantages for the approach are the availability of fast optimising algorithms for solving network formulations, and reduced data collection, processing and storage. The latter is due to the fact that individual distances need not be measured (such as from a map) and stored. A point not mentioned by Krarup is that of flexibility - a new depot location can be introduced without the need to remeasure distances - they can be recalculated from existing co-ordinate data.

The relationship between actual distance, calculated distance and actual transport costs is also an issue dealt with by many writers (e.g. Eilon et al 1971, Krarup et al, 1980). In the finite set approach, distance is usually calculated from the Cartesian co-ordinates of the supply and demand points, using a Euclidean (straight-line) or Manhatten (rectilinear) metric.

Krarup et al found that the error in the objective function resulting from selecting the wrong metric (Euclidean or Manhatten) was not great: less than 1% in experiments using Eilon's data.

To cope with the problem of multiple client visits per trip, two methods are proposed by Eilon: aggregation of the client demand into an amount equal to one trip load, and calculation of expected travelling salesman distances. This latter approach calculates the total distance a travelling salesman would travel visiting his clients based on: area over which the salesman operates;

Euclidean distances between clients and depot; and load factor (clients serviced per trip). The method assumes an ideal situation (square salesman's territory, optimal routes, straight pathways between points) but provides a useful base for estimating distances travelled by milk tankers in collecting milk from a number of farms on one trip. This follows because Roper and Foulds et al have shown how distances derived by tanker scheduling techniques match actual performance reasonably closely (section 3.3).

We now turn our attention to the relationship between expected distances, actual distances and actual transport costs.

A general equation used to relate transport costs to distance is given in Equation 3.1.

Equation 3.1: Transport costs

$$t = (a + bd^f)\, w$$

where
- $t$ = total transport cost
- $a$ = constant
- $b$ = cost per unit weight (or volume) per unit distance
- $d$ = distance
- $f$ = a constant, $0 < f <= 1$
- $w$ = weight (or volume) transported

In practical use, the equation is simplified. Clark (section 3.3) used ($a = 0$, $b = 1$, $f = 1$). In other words, the unit of transport cost was the unit of distance. Benseman used ($a = 0$, $f = 1$) with regionally dependent values of b, calculated from historical company data. Kloth and Blakley used ($f = 1$) and values of a and b derived by Kerchner (1967). Siebert et al carried out a regression analysis and determined that cost per unit carried was correlated with average load per trip, distance travelled, general location of the supply points and type of transport operator (contractor or product distributor). In their model however they subsquently simplified the cost function to a form similar to Kerchner's.

Morris (1978), Love (1972, 1979) and Pruzan (1979) investigated the use of the equation with ($a = 0$) and b and f estimated from actual road data. All the studies indicated that use of a non-unit value for f only slightly improved the cost representation.

It appears that no studies have used Equation 3.1 where all values of a, b and f are non-zero.

Finally, Jacobsen and Pruzan (1978) considered the relationship between 'in-transport' and 'out-transport' distances within the context of location studies. They noted that in agricultural situations, the cost of the 'in-transport' of raw material is often much greater than the 'out-transport' of processed goods, which normally have reduced weight and are easier to handle. Consequently optimal locations may be independent of the out-transport costs. They provided a criterion which can be used to indicate whether it is necessary to consider out-transport costs, and this is used in Chapter 4 to indicate how the larger planning problem can be separated into a number of smaller sub-problems.

## 3.5 Timing of investments and returns

To take account of the effect of time on the optimal location of new facilities various approaches have been proposed. Klein and Kimpel (1967) adopted the finite set approach and discounted future costs and benefits using standard 'present worth' techniques (see for example, Merret & Sykes, 1963). Maximisation of a non-linear objective function was attempted which included economies of scale in depot size, fixed and variable costs and capital outlays. The algorithm did not guarantee a global optimum and for quite small problems computer solution times were very large suggesting that this method is inappropriate in the context of an interactive Decision Support System.

Ballou (1968) also employed a discounting procedure in combination with Dynamic Programming (DP) and a static location model which was solved for each year of the planning period. This model, was concerned with the optimal location of just one warehouse, but the warehouse location was able to change (at a cost) in each year. It was only this latter feature which gave rise to the need for DP formulation, and it has no relevance to the dairy company situation as the cost of relocating a dairy factory is virtually as much as building a new factory.

Adelson (1970) severely criticised discounting procedures arguing for the simpler 'payback criterion' suggesting that if a project returns benefits greater than costs in, say, a four year period, then it will likely rank well on any other economic assessment method. He refers, though not explicitly, to a 'product life cycle' model of an investment and states that:

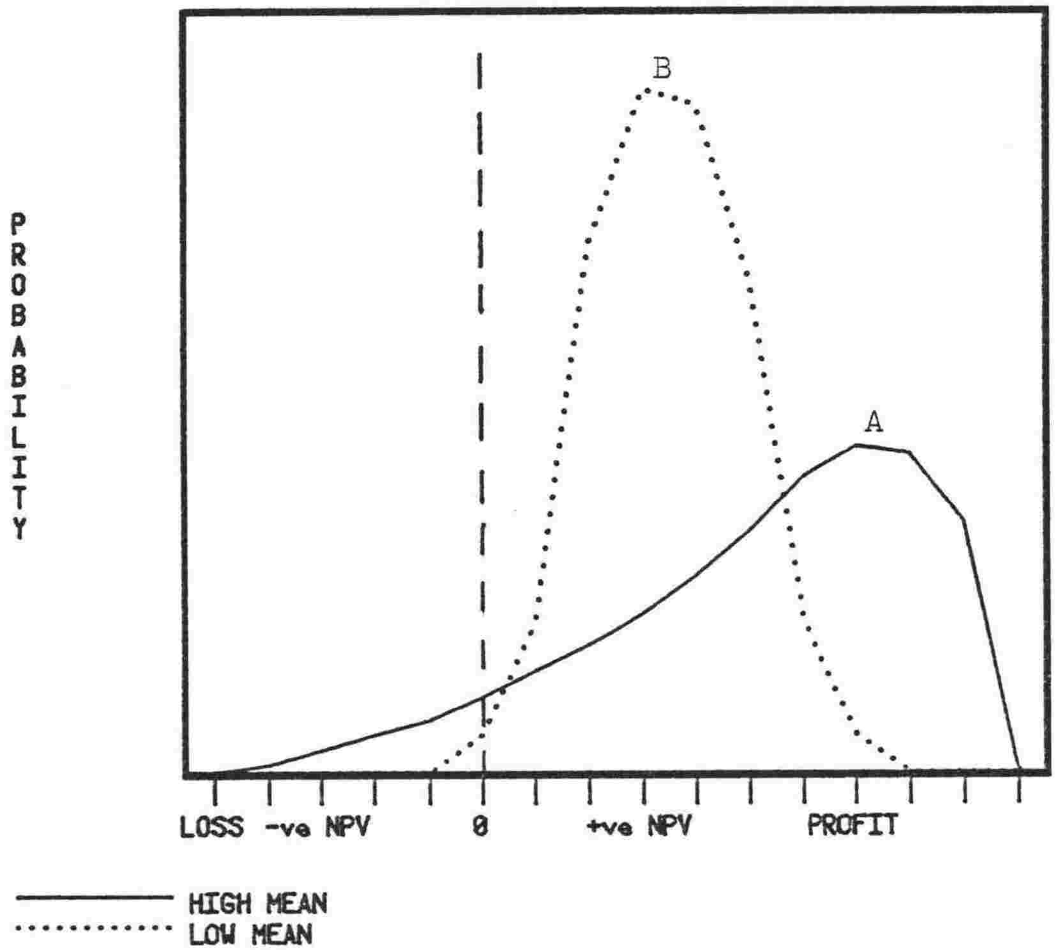
"If one accepts that 'profit' is the reward for successful innovation then since by definition a project is only innovatory during its early years, its principal contribution to profit is going to come during those early years - while, for example, the product is still new enough to command a premium price. In time, the economic system reacts to this profit, and it is 'competed away' by other firms introducing similar products. Thus after a time, a project can only be expected to show 'normal' returns on capital. ... it can be argued that if a project does not show a profit in its early years, it probably never will."

He suggests that if a project genuinely does have a long life, one could modify the payback criterion to consider this feature. For example, a 125% net benefit over 5 years rather than 100% payback in 4 years. His comments are perhaps more appropriate to investments in new technology or existing technology used to produce new products rather than standard dairy factory investments.

DCF is also criticised for failing to deal adequately with events which are uncertain. The two main approaches to this problem are the use of sensitivity analysis and methods which probabilise the calculations. (Ministry of Agriculture and Fisheries, 1977). Figure 3.1 highlights the issue of variability (Adelson, 1971). It shows project A with a high mean expected NPV, but with wide variability including the possibility of loss. Project B shows the converse: a lower mean expected NPV, and lower variability. The project that would be selected depends on the trade-off between risk and return. A large, diversified company could stand

47 (a)

FIG 3.1 PAYOFF BETWEEN RISK AND RETURN



the risk of project A; a small company might not be able to sustain the possibility of a loss, and would thereby choose B.

Techniques are available to deal with probabilising of costs and benefits (Ministry of Agriculture and Fisheries, 1977) but Frost (1976) commented that although the probabilising of calculations has theoretical attractions, his experience was that the method is unworkable, due to the difficulty of attaching probabilities to forecasts, and the extreme difficulty of understanding the results.

Meidan (1978 ) surveying the use of quantitative techniques in warehouse location concluded in a similar manner:

"a relatively unsophisticated model where more flexbility, control and judgement can be applied is ... required".

He suggested a method combining simulation, sensitivity analysis and local optimization techniques (i.e. optimization of a part of the whole system).

## 3.6 Corporate planning models and location studies

General corporate planning models are also used to aid in location type problems. Often they are used to simulate the effect of a new facility on the whole operation of the company, although optimization techniques may be embodied in the overall analytical procedure.

Glover, Jones, Karney, Klingman and Mote (1979) described an integrated production, distribution and inventory model for the

Agrico Chemical Company. The model encompassed four production plants, 78 distribution centres 2,000 clients and four modes of product transport. Because the sales of product were highly seasonal (similar to the New Zealand milk production profile, Figure 2.1) the planning year was divided into 12 months. The model was used for both short and long-term planning. For the latter, a very fast specially-developed mixer-integer LP with embedded network formulation was used, known as PNET/LP. To take account of inventory requirements optimization of the 12 month period as a whole was achieved through a network formulation previously used by Klingman, Randolph and Fuller (1976) in their cotton ginning problem.

Product revenues were not incorporated into the model, though this is not likely to prove very difficult.

A network based model was chosen because of the availability of fast algorithms to cope with large problems, and secondly, because the pictoral nature of the network facilitated good communication with non-specialists. This approach had considerable relevance to the current work although the model structure is somewhat different.

Bender, Northup and Shapiro (1981) described the application of LOGS to planning problems in the International Paper Company. The model is network-based in concept, and allows the user to specify what aspect and level of the company's operations is to be analysed. Data is automatically aggregated depending on the level of analysis. The model uses a standard mixed integer LP, rather than the network programming algorithms described by Glover et al. The timing and phasing of capital expansion programs is not considered. Instead, the model is designed to provide a means of exploring "what if" questions.

## 3.7 Design of interactive systems and the display of results

In the studies previously described, little or no attention has been paid to the design of interactive modelling systems from the viewpoint of the user, and this is a matter dealt with in Chapter 6. This aspect of design draws necessarily upon the field of ergonomics. (See for example, Smith and Wakeley, 1972) These studies are usually related to the design of instrumentation panels for aircraft, power stations and the like, but there are lessons to be learnt in providing a computer-based model which is user-oriented, and seeks to minimise human errors in data entry and result interpretation.

For novel and effective methods for presenting data, Dickinson (1977) is a helpful source, describing a wide range of graphic, mapping and charting techniques. Siebert, Blakley et al and Feldman et al took minor advantage of these techniques. For example, all non-zero product flows from sources to destinations were drawn on a map by these researchers. Clark advanced this technique by ignoring relatively small flows and drawing the thickness of flow lines proportional to the quantity of flow. This aids in data interpretation by concentrating on the more important aspects of the solution. No work on direct computer generation of such graphic results was done.

Software for computer graphics has existed since the mid 1960s, though cost of hardware has tended to limit its application to large organisations, typically those involved in engineering design work, and based around the larger computers then available (Rodgers and Adams, 1976, Newman & Sproull, 1973). In New Zealand, special purpose software has been available for some years, such as the SYMAP program for producing shading maps and isoline maps, and very recently, the SAS/GRAPH (1981) language for business charts and mapping. Until recently, PLOT-10 (Tektronix, 1976) was the only widely availabile general purpose software in New Zealand. This software allows complete flexibility in the design of the graphic applications, but requires special purpose graphics hardware. Since 1979 relatively inexpensive microcomputers equipped with general purpose graphics software have become available, and this has facilitated the wider adoption of computer graphics technology, as demonstrated in this study.

## 3.8 Conclusions

This chapter has surveyed the use of various company location and transportation models and related them to the dairy company's requirements. No model was found which adequately covered all the technical relationships faced by the company with regard to supply, transport, processing, seasonal variation and investment timing. One of the most likely model candidates, Benseman's dairy production planning LP, was limited in its transporation aspect and the computer time required for solution.

Transport costs within the dairy industry were of concern to many authors, and it was found that modelling studies by Roper and

Clark have fairly accurately reflected actual transport activities. The need to develop a model which covers adequately the transport aspect suggests the use of the "hybrid planar network" approach, of Krarup and Pruzan, employing Eilon's expected travelling salesman distance formula as the appropriate distance metric. The hybrid approach also enables a high degree of flexibility in expanding or modifying the base model, and this is seen as a distinct advantage.

The finding by Scott-Morton that successful application of a model is facilitated by a clearly identified and well-understood component of the planning model confirms the suggestion by Meidan to use a model incorporating local optimization within a simulation framework. With the comments by Gass on model validation, this experience points to the idea of integrating a set of essentially standard well-known and reliable techniques rather than the creation of an entirely new mathematical formulation.

The requirement that the model developed should be useful in evaluating a wide range of planning problems suggested the use of Decision Support System concepts. These in turn led to the need for an interactive computer system. Network programming techniques were therefore chosen as being appropriate for modelling in detail the company's transportation and processing operations whilst at the same time providing a high solution speed. The flexibility of the NP structure in terms of the ability to be incorporated readily into a more general model framework (e.g. a heuristic procedure for fixed costs) was an additional favourable feature.

Despite the large quantities of data produced and consumed by the planning models described, only the work of Clark managed to provide effective methods of result presentation. Even so this was achieved manually, for a one-off study.

In accordance with the DSS philosophy automated generation of graphic results is seen as a worthwhile means of enhancing the model's application in a company environment by improving the information (rather than the data) output of the model.

The next three chapters describe the model developed for the NZDC.

# CHAPTER 4

# MATHEMATICAL AND LOGICAL ASPECTS OF THE PLANNING MODEL

## 4.1 Introduction

This chapter begins the description of the planning model developed for the NZCDC. First an overview of the data requirements and data processing steps in the model are given. These data processing steps include both data aggregation and optimisation.

The mathematical and logical components of the model are described which centre around the NETPLAN milk collection and processing model. Further detail is provided about the methods of data aggregation, and finally, the major assumptions regarding byproduct disposal are explored and justified.

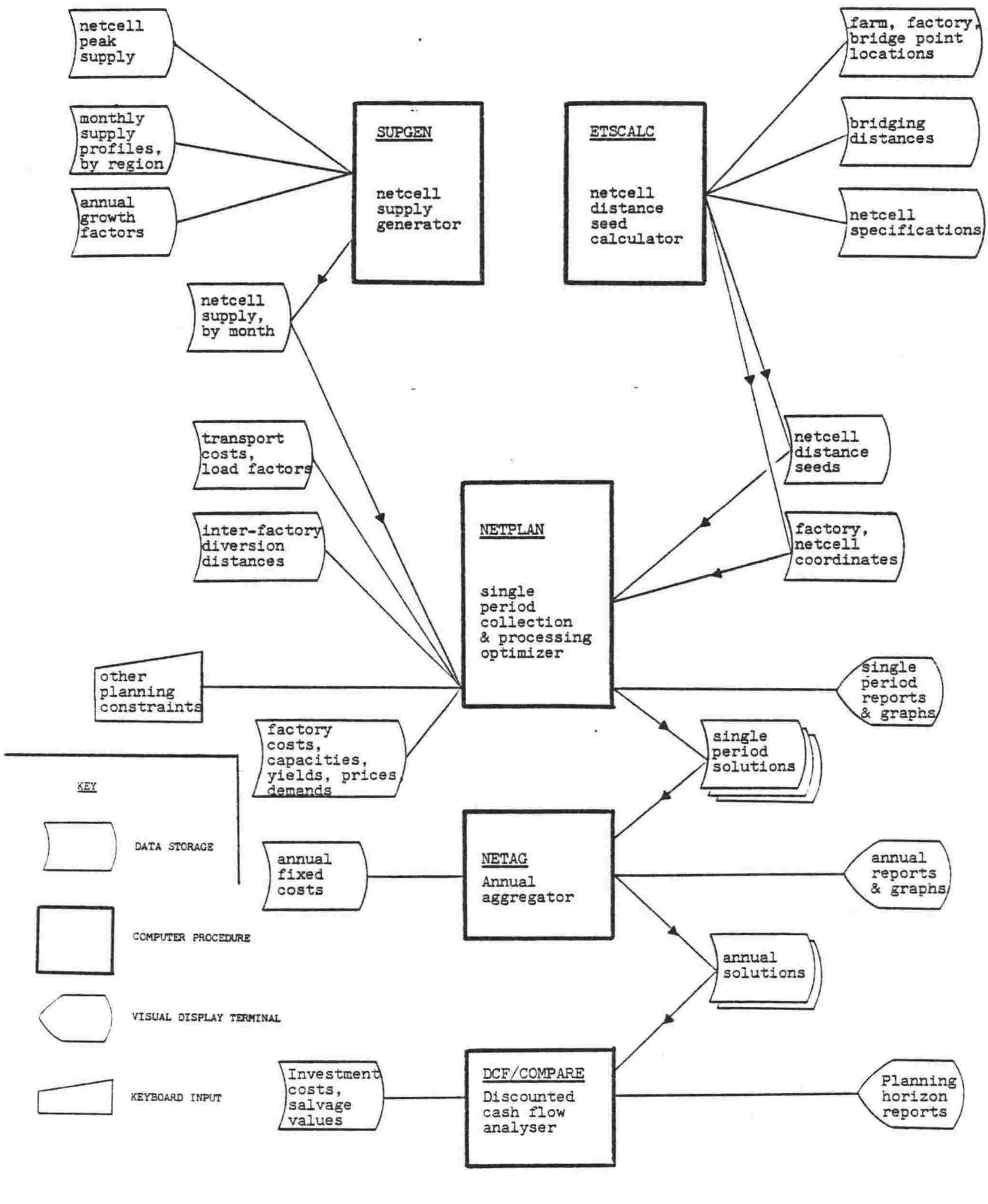
Chapter 5 discusses the issue of fixed costs and investment timing, whilst Chapters 6 and 7 describe the technical and Decision Support System aspects of the model.

## 4.2 Overview of the Model

Figure 4.1 provides a general picture of the data requirements and data processing steps in the model. The figure shows the raw data, data processing steps and intermediate data sets containing aggregated data or solutions. To the lower right are shown the planning reports and graphs produced by the model at various steps.

54 (a)

Fig. 4.1 Outline of the Dairy Company Planning Model



The key component of the dairy company planning model is the NETPLAN milk processing submodel. This network-based submodel optimises the collection of milk from supply netcells (described later) to factories, and allocation of milk to different processes for a selected month. Various constraints are imposed:

(a) All milk supplied must be collected and processed.

(b) Factory and process capacities cannot be exceeded.

(c) Total product requirements must be achieved.

It is also possible to specify factory and process minimum capacities.

A netcell represents the aggregation of a number of farms' supply, and the procedure for aggregation is described in section 4.4.

All data for the model are expressed on a per day basis: the model therefore provides a snapshot of a day's operation. Data was obtained for the average day in each month and the 12 monthly solutions derived are multiplied by the number of operating days in each month and summed to give a year's total. This procedure is carried out by the NETAG (Network Aggregation) submodel.

The NETPLAN model optimises the flow of milk, subject to the constraints described in such a way as to either:

(a) Minimise total variable transport milk collection costs.

(b) Minimise variable processing costs and transport costs.

(c) Maximise net variable revenue (product revenue less process and transport costs).

A variant of the model, NETPLAN/FIXED has the additional capability of minimising fixed costs; this will be discussed in Chapter 5.

Each milk factory has a different input minimum and maximum capacity and one or more processes which convert the milk into one or more products and byproducts. The yields and prices of products vary from factory to factory. (Yields are expressed in units of product made per unit of milk processed.) Process costs are measured as a variable cost per unit of product made.

Each byproduct is assigned a disposal cost or value, per unit produced. The byproduct value is calculated from the net return generated by subsequent processing of the byproduct. However, the NETPLAN milk model itself does not determine how this processing should be done, and this is one limitation of this model. The justification of this approach is given in section 4.5.

Transport costs from netcell to factory are determined from distance seeds (see below), load factors and a cost per kilometre travelled. These last two items do not vary from cell to cell. Instead groups of cells form a transport region and the factors are given for the transport region as whole. The distance seeds comprise two figures for each cell to factory arc, and are determined from the individual farm location co-ordinates, and the cell area in the manner described in section 4.3 and Appendix 1. This procedure is carried out by the ETSCALC sub-model (Expected Travelling Salesman Distance Calculator).

In many situations the actual roading system is such that milk from a cell will pass by a nearby factory on its way to one or more distant factories. In this case it is unnecessary to measure the cell to distant factory distance. Instead only the distance to the closer factory is measured followed by measurement of the inter-factory distance. The inter-factory network of distances, which represents the actual roading system, are referred to as the set of inter-factory diversion arcs.

One advantage of this formulation is that the total number of distance arcs which must be measured is reduced considerably. For example, in the NZCDC NETPLAN milk model, there are 176 supply cells and 14 factories. If every cell was linked to every factory, a total of 2464 distances would be needed. When 89 diversion arcs were used, just 448 collection arcs were required, a total of 537 in all.

This reduction in arcs not only reduces the solution time required for optimising the model, but also simplifies the task of updating the model if a new cell or factory must be added. Solutions to the model also tend to be simpler to interpret.

Figure 4.2 shows the collection transport network defined for the NZCDC milk model and Figure 4.3 shows the diversion network for the same model. In the latter, note that not all factories are connected directly to one another - this again represents the

57 (a)

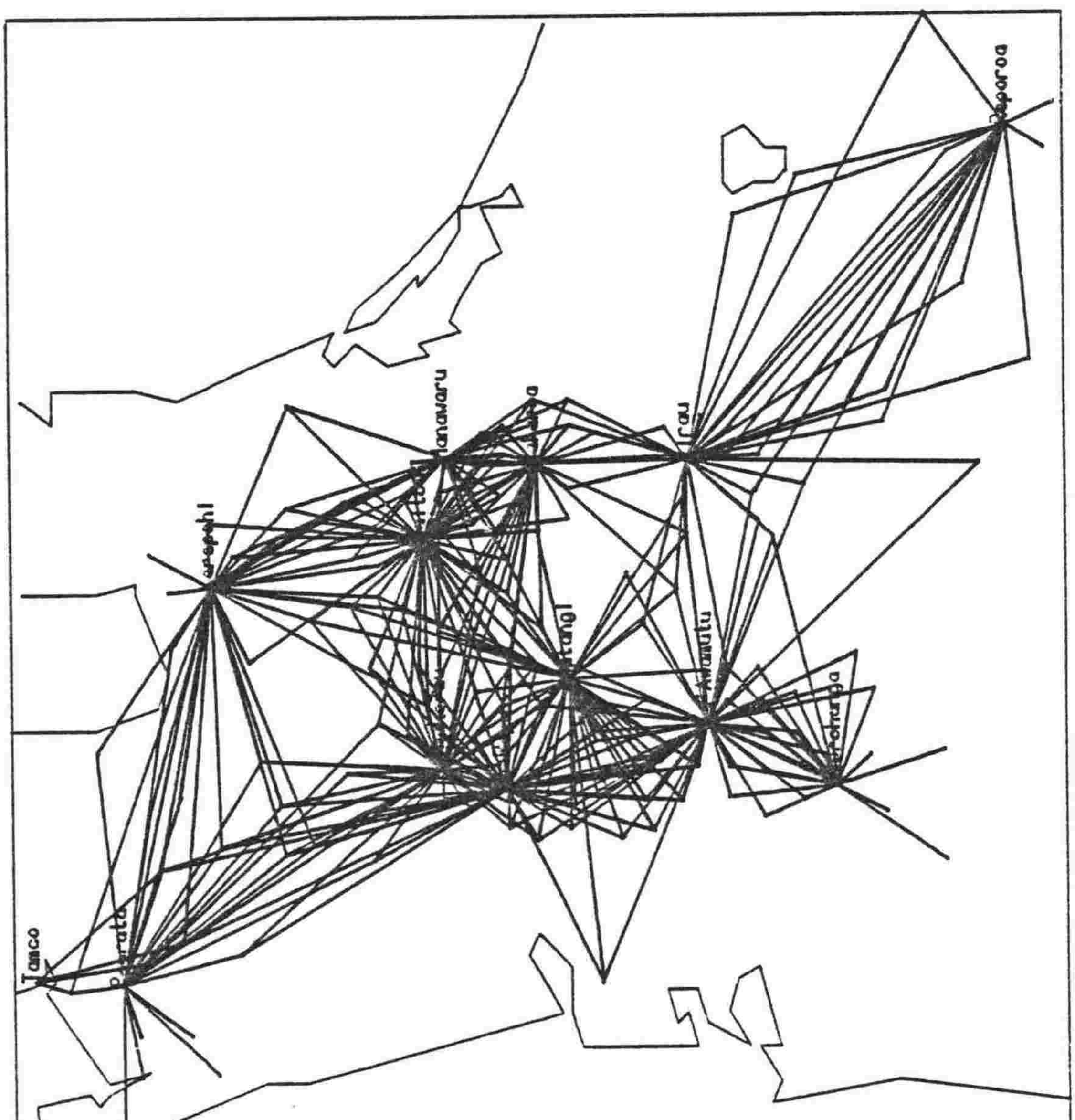


Fig. 4.2 NZCDC Collection Transport Network

57 (b)

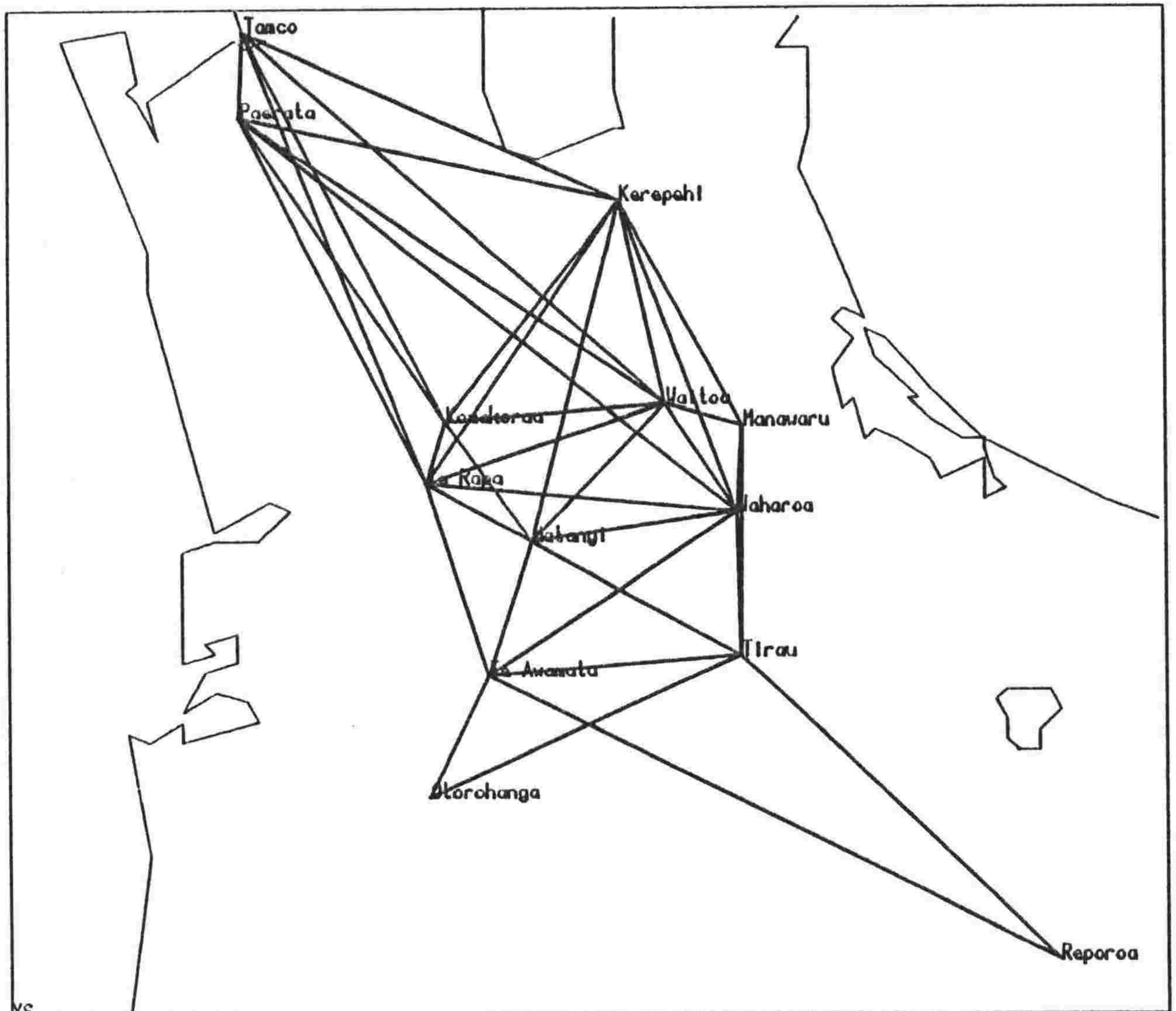



Fig. 4.3 NZCDC Diversion Transport Network

reality of the roading network: to travel from Reporoa to Waharoa, the road must be followed via Tirau.

The NETAG model generates the net variable revenue for a year's operation of a particular planning strategy. Annual fixed costs are also added at this stage to give a total operating cost for the year.

When a more exact result is required, the NETPLAN and NETAG models are used with data forecasts for other years over the planning horizon. A discounted cash flow is used to compare these results with those of a different location strategy. Investment costs are also included at this stage.

Because the NETPLAN model optimizes for individual days rather than for the year as a whole, suboptimal solutions could result when total annual product requirements must be met. For long-range planning this was not considered to be a serious problem because setting annual product demands reduces profitability by enforcing a less optimal transport and processing solution. Instead, long run estimates of product prices should be used which reflect market considerations.

However, the company required the model to have a capability for achieving specified product demands to enable other planning studies to be done, and to compare the model with other procedures. In particular, the capability is necessary when cost minimization (rather than profit maximization) studies are being carried out - the least cost products may have low demand.

The problem of sharing annual product demands to individual months is not too difficult when capacity is limited (as is the case in short-term production planning). At the milk flush, there is generally no spare capacity, so no product constraints can be set. This indicates that the product constaints can only be imposed effectively in the excess capacity months of February through August (see Figure 4.4). The production in April through July is also so small that changes in the monthly product constraints would have virtually no effect on the year's production. This leaves just three months available in which product constraints can be set: August, February and March. Thus the problem of achieving daily product requirements is much reduced. In fact, the NETAG model has been designed so that results from a number of separate NETPLAN monthly runs can be combined easily, thereby allowing the user to quickly determine preferred production constraints for the excess-capacity months.

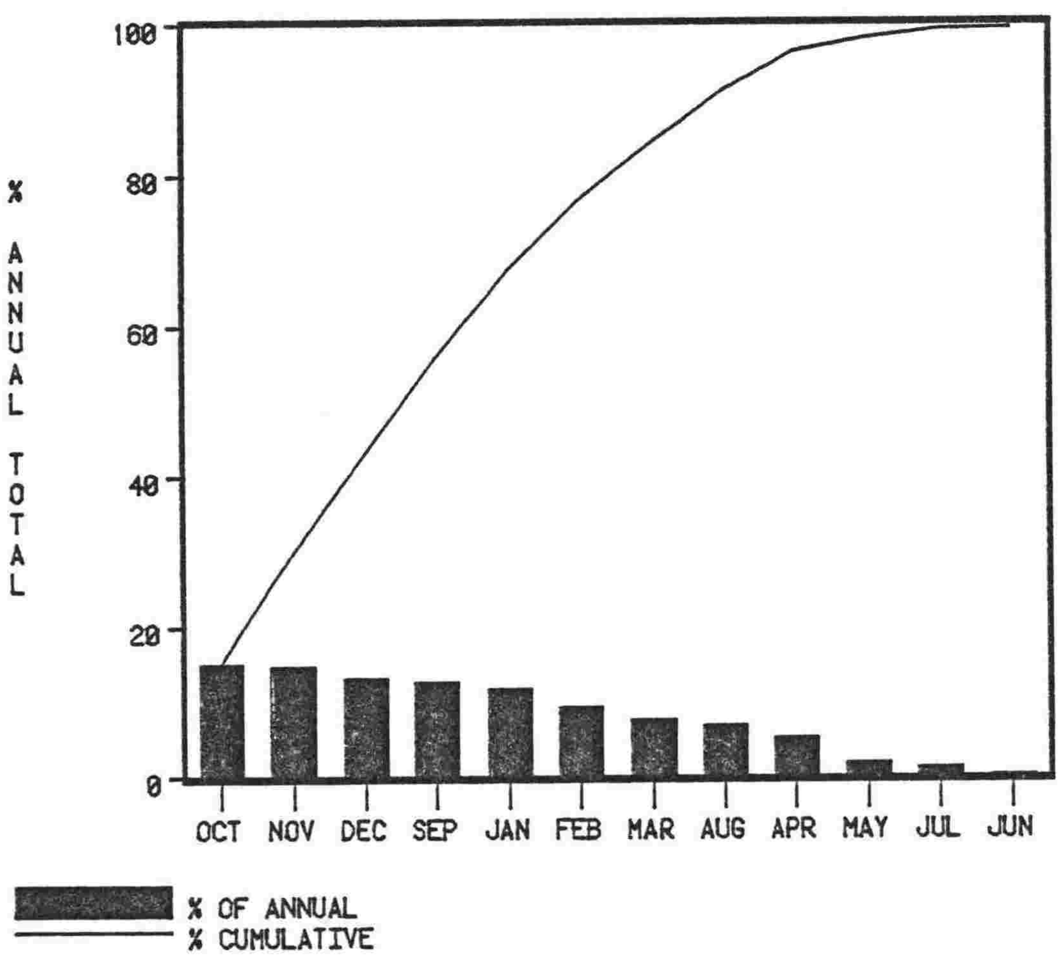
## 4.3 The Mathematical Formulation

The basic network structure of the model, as pictorially represented in Figure 4.5 is mathematically defined in Equation 4.1. The return arc is necessary for the problem to be solved using the Out-of-Kilter Network Programming algorithm, and therefore ($a_i$ = o) for all i. That is all flow into a node must equal flow out of the node.

The network is divided into the seven phases (or stages) shown in Table 4.1. The phase (Roman numeral) will be used as a superscript in the following for convenience of discussion.

59 (a)

Fig. 4.4 CUMULATIVE MILK SUPPLY (80-81)




Source: NZCDC Ltd

59 (b)

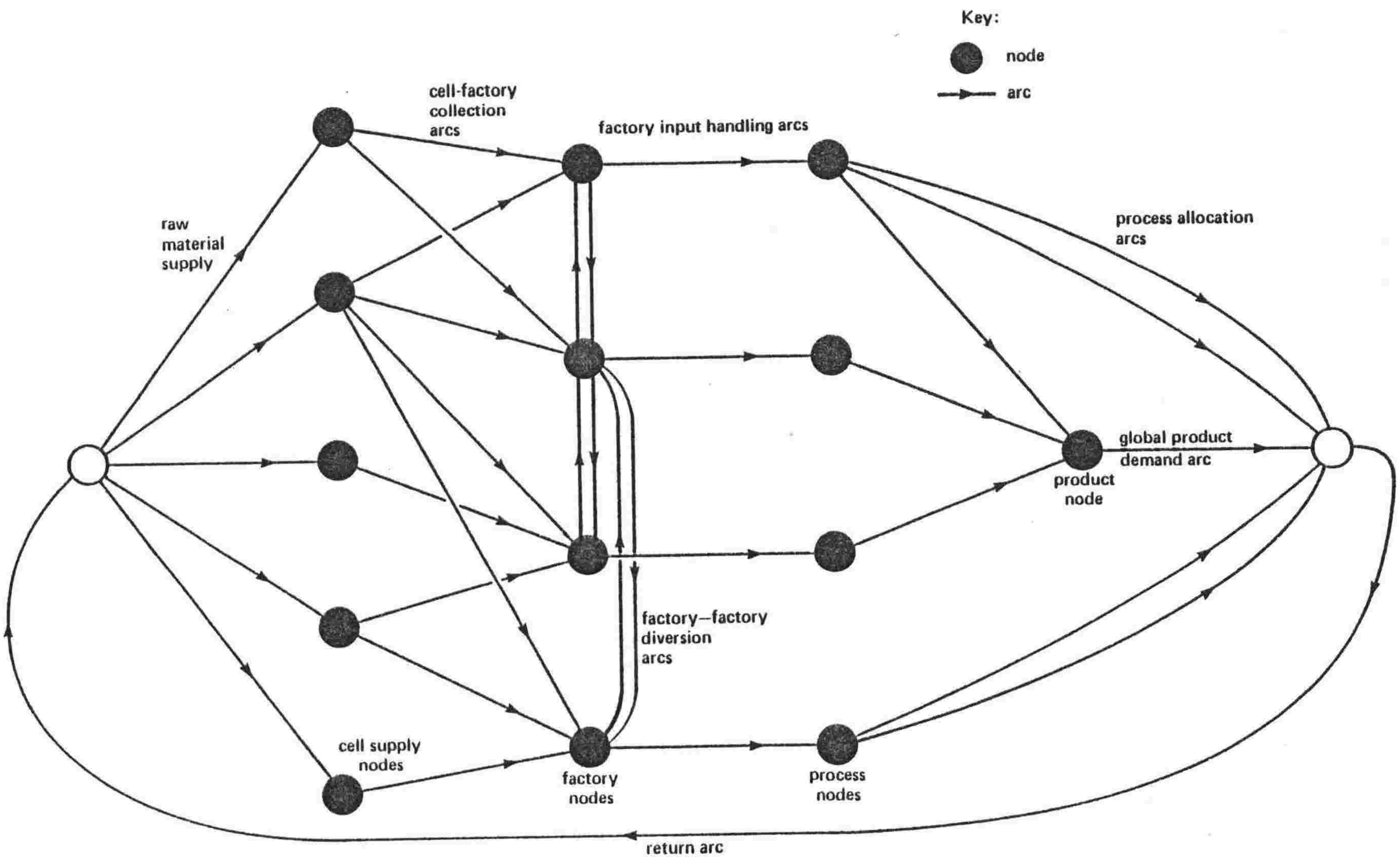



Fig. 4.5 Network Flow Formation

59 (c)

Equation 4.1: Capacitated Minimum Variable Cost Flow Network

Minimize

$$C^V = \sum_{(i,j) \in A} c_{ij} x_{ij}$$

Subject to

a) Conservation of flow at node i

$$\sum_{(i,j) \in A} x_{ij} - \sum_{(j,i) \in A} x_{ji} = a_i, \; i \in N$$

b) Capacity constraints along arc ij

$$l_{ij} <= x_{ij} <= u_{ij}, \; (i,j) \in A$$

Where

$C^V$ = total minimum variable cost

N = the set of nodes

A = the set of arcs

i = a node

ij = an arc directed from node i to node j

$x_{ij}$ = units of flow along arc ij

$c_{ij}$ = minimum allowed flow along arc ij

$u_{ij}$ = maximum allowed flow along arc ij

$l_{ij}$ = cost per unit of flow along arc ij

$a_i$ = units of flow demand at node i (a negative $a_i$ indicates supply)

Table 4.1: Network Phases

| Phase | Description |
|---|---|
| I | Raw material supply |
| II | Cell to factory collection |
| III | Factory to factory diversion |
| IV | Factory input handling |
| V | Process allocation |
| VI | Global product demands |

In the raw material supply phase I, there is no cost of supply, and the lower and upper arc flow constraints equal the flow available at the NETPLAN cell. This gives rise to Equation 4.2.

In the cell to factory collection phase II, the arcs are unconstrained. (The upper arc constraint could be set equal to the source node supply but this was found to have no effect on solution time). The transport cost per kilolitre of milk from cell to factory is calculated prior to the network's solution using Equation 4.3. The equation assumes that we know the total distance that would be travelled by a tanker if all the supply from the cell was sent from cell i to factory j. The total cost of collection from the cell is found by multiplying distance by cost per kilometre. A cost per kilolitre collected is obtained by dividing by the cell's supply. Although the most simple method of predicting total cost from distance is used here it will be noted that any of the more complex functions described by Equation 3.1 could have been used without affecting the network formulation.

60 (a)

Equation 4.2: Phase I (Raw Material Supply)

$$c_{ij} = o, \quad (i,j) \in A^I$$

$$l_{ij} = u_{ij} = s_j, \quad (i,j) \in A^I$$

where

$i$ = 1 = supersource node

$s_j$ = cell supply from cell j, $j \in S$

$S$ = the set of supply cells

60 (b)

Equation 4.3: <u>Phase II (Cell to factory collection)</u>

$$l_{ij} = o, \ (i,j) \ \varepsilon \ A^{II}$$

$$u_{ij} = \infty \ (i,j) \ \varepsilon \ A^{II}$$

$$c_{ij} = \frac{t_r \ d_{ij}}{s_i}$$

<u>where</u>

$i$ = cell supply node, $i \ \varepsilon \ S$

$j$ = factory destination node, $j \ \varepsilon \ F$

$t_r$ = collection transport cost per kilometre travelled in transport region r

$s_i$ = cell supply from cell i

$d_{ij}$ = total distance that would be travelled if <u>all</u> the cell supply $s_i$ was transported to factory j

$F$ = the set of factories

This is because calculation of $C_{ij}$ is carried out before the network is solved.

The total distance $d_{ij}$ is calculated in Equations 4.4 and 4.5 which are a specially modified form of Eilon, Watson-Gandy and Christofides (1971) method for predicting the distance of a travelling salesman's trip. The modification embodies the concept of a 'bridging point' and 'bridging distance' between the netcell and factory (Figure A1.1, Appendix 1) so as to improve the match between predicted distance and actual distance. These equations are explained further in Appendix 1 which also demonstrates the superiority of the method compared with the Centre of Gravity distance estimation method. The completed distance network was verified by comparison with actual total company distances travelled. A high correlation ($r^2$ = 98.8%) was found. (Appendix 1).

In the factory to factory diversion phase III, the arcs are again unconstrained. The transport cost per kilolitre of milk carried between the factories is calculated in Equation 4.6. It should be noted that the milk tanker does not generally stop at the first factory after completing phase II, but rather just passes by the factory, along the actual roading network. A company-wide mean tanker load carried (k) is used rather than a figure varying from transport region to transport region because diversion transport can pass from one region to another. Also milk may be rediverted from the first destination j to another factory further along the diversion network. For the same reasons, the diversion transport cost does not vary from region to region.

61 (a)

Equation 4.4: Total Distance of a Travelling Salesman

$$d_{ij} = \frac{L_{ij}}{\varepsilon_r} + B_{ij}$$

where

$L_{ij}$, $B_{ij}$ = 'distance seeds' for cell i to factory j. (See Equation 4.5)

$\varepsilon_r$ = load factor for transport region r, mean number of farms visited per tanker trip

61 (b)

Equation 4.5: Distance Seeds

$$L_{ij} = 2n_i b_{kj} + 1.7Z_{ik}$$

where

$Z_{ik}$ = Sum of Euclidean distances from all farms in supply cell i to a bridging point k in or near cell i

$n_i$ = total number of farms in cell i

$b_{kj}$ = bridging distance. The one-way actual road distance from bridging point k to factory j in kilometres

and

$$B_{ij} = 1.035 Z_{ik}^{\frac{1}{2}} P_i^{\frac{1}{4}}$$

where

$P_i$ = area over which the farms in cell i are scattered, in square kilometres

Equation 4.6: <u>Phase III (Factory-Factory Diversion)</u>

$$l_{ij} = o, \ (i,j) \ \varepsilon \ A^{III}$$

$$u_{ij} = \infty, \ (i,j) \ \varepsilon \ A^{III}$$

$$c_{ij} = \frac{2 \ t \ b_{ij}}{k}$$

<u>where</u>

$i$ = origin factory

$j$ = destination factory

$t$ = diversion transport cost per kilometre

$b_{ij}$ = one-way actual road distance between factory i and factory j, kilometres

$k$ = mean company tanker load carried, kilolitres

The factory input handling phase IV simply specifies the maximum milk flow that can be handled by the factory. In addition, minimum required flows can be specified (Equation 4.7). A general input handling cost per kilolitre of milk could be specified but in practice this facility was not used.

This phase could be eliminated from the network formulation. However its inclusion is necessary for the inclusion of fixed factory processing costs (Chapter 5). The computer programming is also simplified for tasks such as closing a factory, or determining from the network solution the factory's total actual input flow.

The process allocation phase V determines by which process the milk input should be processed. This is done on the basis of process minimum and maximum capacities, the net cost per kilolitre of milk derived from process costs, product prices, byproduct values and product yields, as shown in Equation 4.8. The destination node in this phase is the supersource node except when the product or byproducts of the process are subject to a global production constraint, in which case the milk flows into phase VI. In this phase, all process arcs which make the same product are combined together at the global product node. The constraints on the arc emanating from this node are set so as to ensure that the collective flow through the processes will give rise to the required total company production of the product (skim milk powder, cheese, or casein) (Equation 4.9).

It is possible to set simultaneous global constraints on different products when they are made by separate processes, though this is

62 (a)

Equation 4.7: Phase IV (Factory Input Handling)

$$l_{ij} = \lambda_i$$

$$u_{ij} = \mu_i$$

$$c_{ij} = o$$

where

$i$ = factory input node

$j$ = process origin node at factory i

$\lambda_i$ = minimum required flow at factory i, kilolitres

$\mu_i$ = maximum allowed flow at factory i, kilolitres

62 (b)

Equation 4.8: Phase V (Process Allocation)

$$l_{ij} = \lambda_{if}$$

$$u_{ij} = \mu_{if}$$

$$c_{ij} = \psi_{if} Y_{1if} - \sum_{p=1,P} w_{pif} Y_{pif}$$

where

$i$ = process node i at a factory f

$j$ = supersource node or global product demand node

$\lambda_{if}$ = minimum required flow at process i, kilolitres

$\mu_{if}$ = maximum allowed flow at process i, kilolitres

$\psi_{if}$ = process cost at process i, cents per unit of product

$Y_{pif}$ = yield of product (when p=1) or byproduct (when p>1) per kilolitre of milk

$w_{pif}$ = factory gate selling price in cents per unit of product (when p=1). Factory gate net value of byproduct (when p>1)

62 (c)

Equation 4.9: Phase VI : (Global Production)

$$l_{ij} = \frac{q_{p\lambda}}{Y_p}$$

$$u_{ij} = \frac{q_{p\mu}}{Y_p}$$

$$c_{ij} = o$$

where

$i$ = process allocation node

$j$ = supersink

$q_{p\lambda}$ = minimum quantity of product p required by company as a whole, in product units

$q_{p\mu}$ = maximum quantity of product p required by company

$Y_p$ = yield of product p in units of product per kilolitre not shown in Figure 4.5.

Product Yields

Equation 4.9 assumes that the product yield is identical from process to process. This is generally not true. For this reason it was necessary to employ an iterative procedure which is summarised in Table 4.2.

Table 4.2: Iteration procedure for global product demands

| Step | Action |
|---|---|
| 1 | Calculate mean company yield of product |
| 2 | Establish phase VI arc constraints using Equation 4.9 |
| 3 | Solve network |
| 4 | Calculate actual production of product using process flows and product yields |
| 5 | Test termination criteria. |
| 6 | If termination criteria are not satisfied, re-estimate company yield and go to step 2. |
| 7 | Otherwise end. |

The iteration procedure is carried out very rapidly because each time the network is solved (step 3) the previous network solution is used as a starting basis. The termination conditions are:

(a) The company yield used in Equation 4.9 must be similar to the resulting average company yield derived from the network's solution.

(b) The total resulting yield of product must be within the required constraints.

Further details of the iteration procedure are given in Appendix 2.

A further assumption is that the quality of milk from all cells in a given period is identical with respect to fat, protein, other solids and water. In fact the quality of milk varies slightly from supply region to region due to climatic variations. At a factory the yield of product and byproduct from the milk may not achieve the theoretical yields predicted from the incoming milk's composition. Reasons for this include differences in process conversion rate efficiencies due to the wide age range of the technology. Thus two factories provided with identical milk quality will produce different amounts of product. It was decided to assume yields for each individual factory calculated on the basis of that factory receiving milk from its local supply region. This tends to reflect reality in the peak flow months (when the problem is virtually a transport minimisation) but less so in the offpeak months when large milk diversion could occur, in response to differential net revenues obtained from the milk's processing.

## Total Annual Cost

The previous discussion has been based around the formulation for a single period. In fact, the following parameters vary from month to month due to seasonal changes:

| | |
|---|---|
| s | Cell supply |
| E | Load factor, farms visited per tanker trip |
| d | total cell to factory distance (calculated from E, Equation 4.4) |
| k | mean tanker load carried |
| y | yield of product or byproduct |

The NETAG model carries out the simple arithmetic task of multiplying the individual daily minimum variable costs (obtained by Equation 4.1) by the number of operating days in the month represented. Annual fixed operating costs for each factory are added unless the factory processed no milk at any period during the year. See Equation 4.10.

## Pre-solution Feasibility Checks

The Out-of-Kilter algorithm employed to solve the network either returns the optimal solution or is infeasible for one of many reasons. It is helpful to be informed of these reasons and so pre-solution feasibility checks are carried out. These are:

(a) Total maximum processing and factory capacity greater than or equal to supply.

65 (a)

Equation 4.10: Annual Cost Aggregation

$$C = \sum_{n=1,12} C_n^v q_n + \sum_{j \varepsilon F} C_j^f y_j$$

where

| | | |
|---|---|---|
| C | = | total annual cost |
| $C_n^v$ | = | variable cost for period n |
| $q_n$ | = | operating days in period n |
| $C_j^f$ | = | annual fixed cost of operation for factory j |
| y | = | o when $\sum_{n=1,12} x_{ijn}^{IV} = 0$<br>1 otherwise. (See Equation 4.7) |
| F | = | the set of factories |

(b) Total supply greater than or equal to total minimum factory, process or product requirements.

(c) For each global product constraint, the total maximum amount of product that can be made must be greater than or equal to the minimum amount of product required.

These checks are easily programmed and carried out because of the manner in which the network is formulated as a series of phases.

Other causes of infeasibility are:

(a) A supply cell is not connected to any factory at all.

(b) Diversion road network does not allow complete freedom for supply to travel to any factory and local supply is too great for local (undiverted) capacity to handle.

(c) Certain combinations of minimum process or factory capacities and global product constraints. For example, the minimum process capacities at all cheese factories may be set greater than zero whilst global product demand for cheese is set to zero.

Cases (a) and (b) are dealt with in the initial model building phase. Case (c) is particularly difficult to determine but experience has shown that if the user is alert to this possibility, he is soon able to locate the cause of infeasibility.

## Model Size and Structural Parameters

The size of the network model, in terms of arcs and nodes is an important consideration so far as computer solution time and computer memory are concerned. The size can be calculated from just six 'structural parameters', as shown in Table 4.3. For the NZCDC milk model:

| | | |
|---|---|---|
| NCELLS | = | 176 |
| NCOLLECTIONARCS | = | 448 |
| NDIVERSIONARCS | = | 89 |
| NFACTORIES | = | 14 |
| MAXPROCESSES | = | 5 |
| NPRODTYPES | = | 8 |

From this data, the model has 806 arcs and 214 nodes. Maximum solution time for this model was 6.5 seconds (Central Processing Unit time) on an IBM 3033, for a single period. Solution times are reduced when a previous solution flow basis is used to start the optimization for subsequent periods.

Table 4.3: Network Model Size

| Network Phase | Arcs Incurred | Nodes Incurred |
|---|---|---|
| I Supply | NCELLS | NCELLS |
| II Collection | NCOLLECTIONARCS | - |
| III Diversion | NDIVERSIONARCS | - |
| IV Factory input | NFACTORIES | 2*NFACTORIES |
| V Process allocation | MAXPROCESSES* NFACTORIES | - |
| VI Global production | NPRODTYPES | NPRODTYPES |
| - Return arc | 1 | 2 |

where:

| | | |
|---|---|---|
| NCELLS | = | total number of supply cells |
| NCOLLECTIONARCS | = | total number of cell to factory collection transport arcs |
| NDIVERSIONARCS | = | total number of inter-factory diversion arcs |
| NFACTORIES | = | total number of factories |
| MAXPROCESSES | = | total number of processes per factory (maximum) |
| NPRODTYPES | = | number of different types of products and byproducts |

A few other structural parameters are required to complete the model and these are:

| | | |
|---|---|---|
| MAXPRODUCTS | = | maximum number of products made by any one process |
| NREGIONS | = | number of transport regions |
| NPERIODS | = | total number of periods |

For the NZCDC model, these take the values 3, 3 and 12 respectively.

Network Building

Great flexibility and reliability in the initial construction and subsequent updating of the model's data is achieved by the design of the network as a series of phases, and the employment of structural parameters. These two features permit the data to be presented to the model using only relative node numbers within each phase. Network building equations combine the structural parameters and relative node numbers to produce the network flow formulation in terms of absolute node numbers required by the Out-of-Kilter algorithm. The network building equations are given in Tables 4.4 and 4.5.

For example if a collection distance arc (Phase II) is specified from a cell with relative node number i to factory with relative node number j then the absolute node values are:

$$i_a = N^{II} + i - 1$$

$$j_a = N^{III} + j - 1$$

If this is the nth arc specified in phase II then the absolute arc number is:

$$n_a = A^{II} + n - 1$$

Table 4.4: Starting (Source) Nodes by Phase

| Phase | Absolute Node Number | Variable |
|---|---|---|
| I | 1 (supersource) | $N^{I}$ |
| II | 2 | $N^{II}$ |
| III | $N^{II}$ + NCELLS | $N^{III}$ |
| IV | $N^{III}$ | $N^{IV}$ |
| V | $N^{IV}$ + NFACTORIES | $N^{V}$ |
| VI | $N^{V}$ + NFACTORIES | $N^{VI}$ |
| Supersink | $N^{VI}$ + NPRODTYPES | $N^{max}$ |

Note: (a) Source nodes for the diversion phase are identical to the factory input nodes.

(b) The supersink starting node is equal to the total number of nodes in the network.

Table 4.5: Starting Arcs by Phase

| Phase | Absolute Arc Number | Variable |
|---|---|---|
| I | 1 | $A^{I}$ |
| II | $A^{I}$ + NCELLS | $A^{II}$ |
| III | $A^{II}$ + NCOLLECTIONARCS | $A^{III}$ |
| IV | $A^{III}$ + NDIVERSIONARCS | $A^{IV}$ |
| V | $A^{IV}$ + NFACTORIES | $A^{V}$ |
| VI | $A^{V}$ + MAXPROCESSES*NFACTORIES | $A^{VI}$ |
| Return Arc | $A^{VI}$ + NPRODTYPES | $A^{max}$ |

Note: The return arc is equal to the maximum number of arcs in the network.

## 4.4 Supply Aggregation

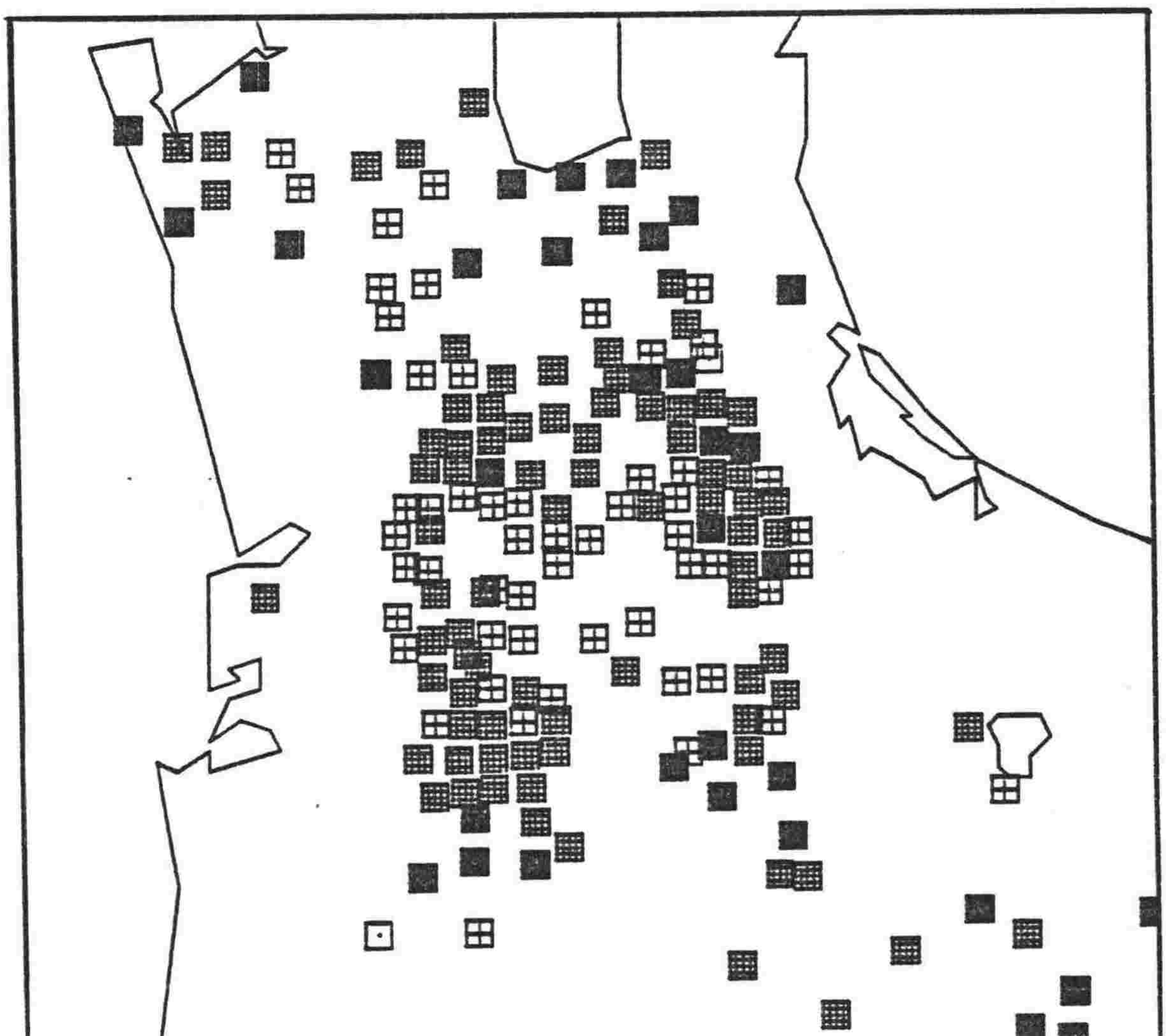
The fundamental unit of milk supply is the farm. However it is necessary to aggregate the farms into a larger supply unit because more than one farm is collected on a single trip by a milk tanker.

The farms were aggregated into NETPLAN model cells (netcells) on the basis of: number of farms; topographical features; and choice as to how many factories the supply could be sent. Figure 4.6 shows the location of each netcell for the model.

For the purpose of generating supply projections, (using the SUPGEN program) nine supply regions were formed which comprise

72 (a)

Fig. 4.6 NZCDC Location of Net Cells



Note: Density of shading proportional to flush milk quantity.
Size of squares is not related to actual area.

cells with similar monthly milk production profiles and annual growth rates. This eliminated the need for individual profiles for each cell and enables changes to supply projections to be carried out more easily.

Additionally, three transport regions were set up each of which comprised cells having similar transport characteristics, such as cost per kilometre, and tanker load size.

The actual utilised tanker capacity varies from month to month. In April, for example, supply per farm is so small that theoretically the milk from 41.6 farms could be collected on one trip, compared with five farms per trip in October. Table 4.6 presents typical data. In October, tanker capacity limits the number of farms that may be visited. In April, the practical difficulty of the scheduling task required to achieve the theoretical number of visits means that a smaller tanker utilisation is achieved. Also, although maximum utilisation is desirable in October, in order to minimise the number of tankers and drivers, this is not so necessary in the off-peak periods (the tankers are owned by the company). The duration of the collection run is important in the off-peak periods, for milk quality reasons and the need for factories to receive supply early on in the day. A tanker run to 40 or more farms would take too long.

The impact of these features is that the cost per kilolitre of milk carried increases in the periods away from the peak, and so must be recalculated each period using Equations 4.3 and 4.4.

Table 4.6: Tanker Loadings by Month

| Month | % of Maximum Farm Supply | Actual Farms Visited per Trip | Theoretical Farms Visited per Trip | % Tanker Utilisation |
|---|---|---|---|---|
| October | 100 | 5 | 5 | 100 |
| February | 52 | 7 | 9.6 | 73 |
| August | 45 | 7.5 | 11.1 | 68 |
| April | 12 | 12 | 41.6 | 29 |

Note: Data refers to tanker with maximum capacity of 9.5 kl.

## 4.5 Byproduct Processing

The relationship between the 'in-transport' of raw material and the 'out-transport' of processed goods on the optimal site location was discussed in section 3.4. Cream is one of the more important products of a dairy factory because it accounts for one-half of the company's revenue after subsequent processing (see Figure 2.2). The Jacobsen-Pruzan location criterion (r) was calculated using Equation 4.11 with the following typical company data:

74 (a)

Equation 4.11: Jacobsen-Pruzan location Criterion, r

$$r = \frac{t_o \; w_o \; c_o}{t_i \; w_i \; c_i}$$

where

$r$ = Jacobsen-Pruzan location criterion

$t_o$ = out-transport costs per unit weight per unit distance

$w_o$ = weight of out-transport sent to major demand client

$c_o$ = out-transport distance correction factor

$t_i$ = in-transport costs per unit weight per unit distance

$w_i$ = weight of in-transport from neighbourhood supplier-clients

$c_i$ = in-transport distance correction factor

$t_0/t_1$ = 0.7212 (based on milk tanker average loading of 60%)

$C_0/C_1$ = 1

$W_0/W_1$ = 0.049 (the cream component of milk)

The resulting value of $r = 0.035$ is far below the cut off criterion of 0.25 from which it is concluded that the subsequent distribution of cream will have no affect on the optimal location of a milk processing factory.

Although Equation 4.11 assumes a planar distance formulation and that the farms are homogenously located within a circular area the r value is so well below the cut off criterion that these assumptions can be ignored safely.

Whey Production

In comparison with the highly-valued cream, the whey produced by cheese and casein manufacture has until very recently made only a very small contribution to the company's revenues. This is because the low solids content (5.2% to 6.4% wt/vol) and low value of product (powdered whey stockfood) made transport away from a milk factory uneconomic.

The Jacobsen-Pruzan criterion is calculated to range from 0.55 for a cheese factory and 0.59 for a casein factory indicating that the transport of whey from a milk factory would have some effect on the optimal location of a new milk factory.

More recently, whey has been fermented to give ethanol which has a high market value. To reconcile this and the previous point, the company locates this fermentation technology at its whey producing plants rather than establish a remote, stand alone plant (a benefit of this strategy is the sharing of utilities such as steam). In the immediate short term, a planning problem exists in that whey from a plant without the fermentation technolgy could be transported during non-peak production periods to the ethanol plants. For the longer-term planning horizon this problem can be disregarded as whey processing technology with an equally high economic return is introduced at the milk plants.

The economic value assigned to byproducts is an important factor not so much for location, but for process capacity allocation (see Equation 4.8). For example, a relatively high value for cream could encourage milk to be allocated to skim milk powder at the expense of wholemilk powder (where virtually no cream byproduct is made). Although the simplest approach is to assume that the byproduct is transported to the closest available processing facility this was found to be unrealistic from an optimising point of view in the case of cream.

Using a NETPLAN-based formulation for profit-maximising the distribution and processing of cream, it was found that the cream distribution pattern varied widely form month to month. Table 4.7 shows the major destination of cream from just one milk factory.

Table 4.7: Optimal Destinations of Cream from Kerepehi

| Month | Destination |
|---|---|
| June | - |
| July | Waharoa |
| August | Waharoa |
| September | Tuakau, Waharoa |
| October | Tuakau, Frankton |
| November | Tuakau, Frankton |
| December | Tuakau, Frankton |
| January | Tuakau, Waharoa |
| February | Waharoa |
| March | Waharoa |
| April | Waharoa |
| May | - |

The experiment showed that the company mean value per kilolitre of cream maintained a reasonably constant value from month to month (ranging from $539 to $542/kl) despite wide variation in the net value of cream at the demand points (butter or AMF factories) which ranged from $534 to $548/kl. This finding suggested the use of a standard cream value to be used at all cream producing factories. This approach is also justifiable on the grounds that over the longer-term planning horizon, less-efficient cream processing facilities would be replaced by more efficient ones thereby reducing the variation in cream values. Subsequent sensitivity tests involving varying the cream value in the NETPLAN milk model showed no significant variations in process allocation or factory allocation of milk when long-run prices were used.

In order to maintain consistency in the modelling approach, the same assumption of a standard value for whey was also proposed. Despite the far greater variation in demand point whey values the small contribution to total company revenue (less than 5%) makes this assumption acceptable.

## 4.6 Conclusions

This chapter has given an overview of the planning model and described in detail a network flow optimization model for milk collection and processing. The mathematical formulation was described with particular emphasis on the logical validity of the construction. In conjunction with Appendix 1, the validity of the data used in the transport component of the model was established. Sensitivity experiments with the model established the validity of the various assumptions regarding byproduct disposal. The validity of process cost, yield, price, and capacity data was regarded primarily as the company's responsibility and this was emphasised to the company during the model's implementation. Chapter 6 will describe the 'software interface' features of the model which enabled the company to carry out its own evaluations. Chapter 7 reports on a comparison of the model with other company planning procedures. Before these chapters, however, Chapter 5 will continue the development of the mathematical formulation with regard to fixed costs and overtime costs.

# CHAPTER 5

# INCORPORATION OF FIXED COSTS, ANNUAL COSTS AND OVERTIME COSTS INTO THE MATHEMATICAL FORMULATION

## 5.1 Introduction

This chapter develops on the mathematical formulation described in Chapter 4 by considering the various fixed costs and overtime costs involved in the location planning problem.

Because overtime costs are convex with respect to ordinary time processing costs, they are readily incorporated into the network formulation described in Chapter 4. Daily fixed costs, such as plant preparation, shutdown and shift labour charges are not directly incorporable into the network and require an enumerative technique such as Branch-and-Bound in order to achieve optimality. This approach was considered inappropriate in view of the requirements for a fast DSS. A heuristic approach was instead developed which has the advantages of high solution speed and predictable computational effort whilst giving an estimate of the maximum degree of suboptimality.

Annual fixed costs and investment costs are considered separately, rather than amortized into the daily fixed charge. The reasons for this are given. The use of Discounted Cash Flow to compare different planning scenarios is described in a manner which assists in evaluating the timing of investments. Finally, methods for identifying a good set of candidates to be included in the feasible set are given.

## 5.2 Non-linear processing costs

Figure 5.1 shows a total cost curve and gross revenue curve for a single process factory. The fixed charge represents the daily setup/shutdown cost for the factory and the cost of operation of the day's shift. Dealing with the ordinary and overtime costs involves incorporating two process arcs into the network formulation and is discussed shortly. The inclusion of a fixed charge, however, requires a more elaborate method of solution particularly when high solution speeds are required.

### Ordinary and overtime costs

To model the ordinary time and overtime costs associated with a process two arcs are incorporated for each process in phase V of the network. (See Section 4.3). On one arc is specified the gross revenue less ordinary time variable processing cost, and ordinary time capacity. The second arc has the gross revenue less overtime cost specified and a maximum capacity equal to the overtime capacity (see Figure 5.2). Since the overtime cost is greater than the ordinary time cost, milk will always be allocated to the ordinary time arc before the overtime arc. Note that the maximum capacity on the factory input arc must be set equal to the sum of ordinary and overtime capacities.

### Total Revenue function

The daily cost of operating the shifts at the factory is a fixed charge payable only if a non-zero flow is handled by the factory input handling arc. Combining this charge with the variable costs described gives rise to the total revenue function for a single-process factory as shown in Figure 5.3. The approach is generalized to account for multiprocess factories by incorporating two arcs for each process instead of the single process arc shown in Figure 4.5

Note that it is possible for a factory to be forced to operate below the breakeven point for one of two reasons: all milk supplied to the company must be processed; production may be required to meet global product demands.

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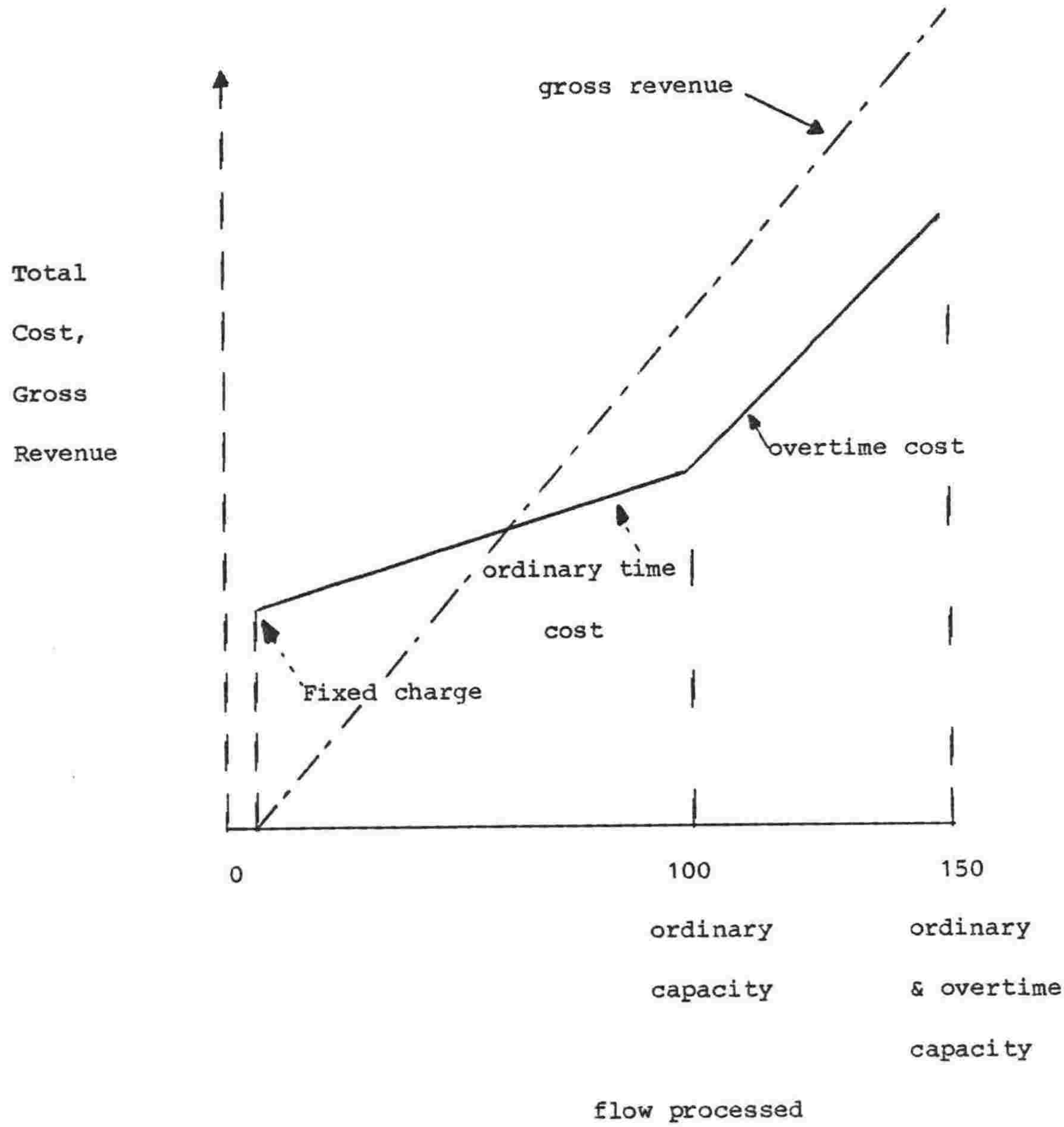
Figure 5.1 Total cost for a single process factory



83

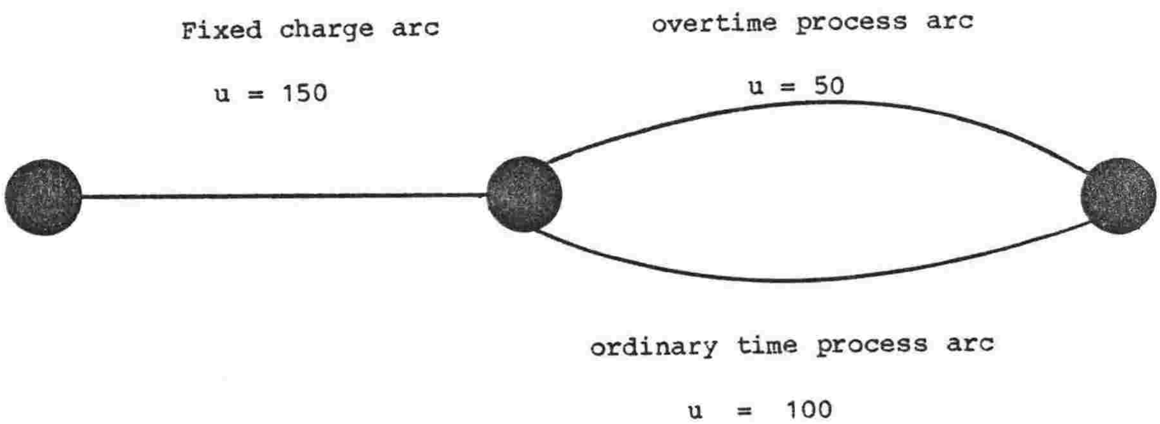
Figure 5.2 Inclusion of overtime costs

Phase IV

Factory Input

Phase V

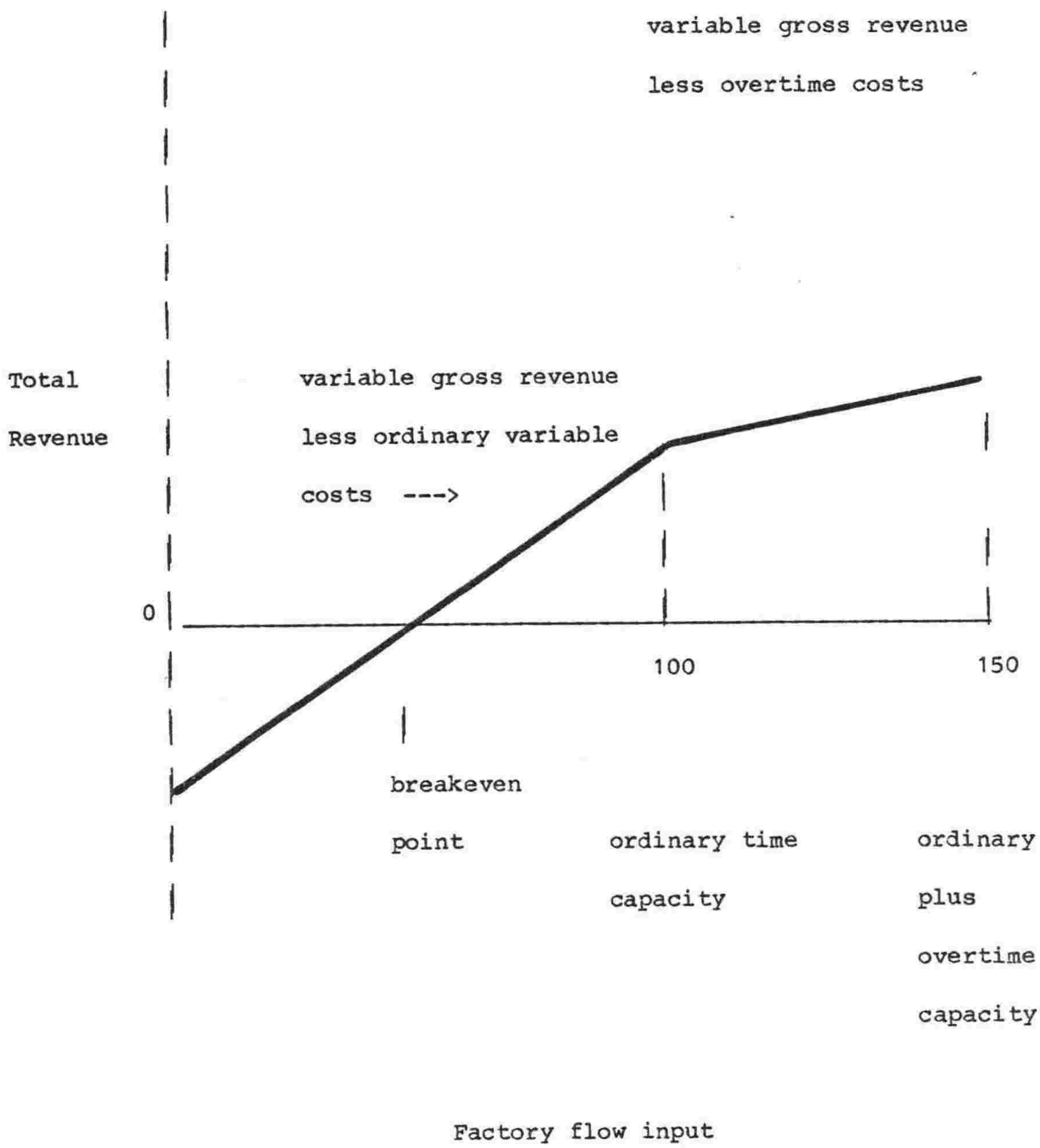
Process Allocation




Note : only one process at the factory is shown

84

Figure 5.3 Total revenue at a single process factory with fixed charge and overtime



## 5.3 Solving the Fixed Charge Problem

Section 3.4 discussed optimal and heuristic approaches to solving the fixed charge problem. The method adopted here is a modification of Sa's (1968) heuristic in combination with features selected from the works of Barr (1979), Gray (1968) and Balinski (1961). The method was developed because of the need for a fast solution process due to the interactive requirements of a DSS approach. The solution time required is generally proportional to the number of network problems (NPs) which must be solved. Using Sa's method, the number of NPs is of the order of $n + n^2/4$ where n = number of fixed charge arcs. For an optimizing approach (e.g. Branch-and-Bound) the evidence suggested (Barr, Kennington, 1976) that there was no reliable way of predicting solution time. The possibility of very long solution times was not seen as an appropriate feature for incorporation into a DSS (Section 3.2).

Sa's method involves a cycle of 'drop', 'add' and 'swap' phases. Whenever improvements to the objective function cost are found in either of the last two phases, the procedure returns to the 'drop' phase and proceeds through the cycle again. Eventually no improvements are found in the 'swap' phase and the procedure terminates.

The first improvement to the method involves using Balinski's relaxation to start with a flow basis nearer to the optimum than when only variable costs are used. The network is assigned relaxed arc costs as shown in Equation 5.1. Balinski showed that when the NP is solved with these relaxed costs, the conditions

85 (a)

Equation 5.1: <u>Balinski's Relaxation for Arc Costs</u>

$$c' = c^v + c^f/u$$

<u>where</u>

$c^v$ = variable cost

$c^f$ = fixed cost

$u$ = upper capacity on arc

shown in Equation 5.2 hold. Of interest is that $t_{r1x}$ gives a bound to the best value that can be found for $T_{opt}$, the true cost of the optimal solution.

The next improvement is to modify the 'drop' phase by working on the flow basis produced by the Balinski relaxation. This involves unrelaxing arcs by either forcing them out or into the basis flow in a manner similar to that described by Barr et al in their Branch-and-Bound procedure. First, a candidate arc is dropped (or forced out) by assigning a large cost (Big M method). If this fails to improve upon the best T so far found ($T_{inc}$, the incumbent true total cost) then the candidate arc is assigned its true variable cost and thereby left in the basis. A candidate arc is found amongst the set of fixed charge arcs which have relaxed costs rather than variable costs assigned. Selection of the candidate is through use of the 'maximum deviation from the relaxation' criterion. The deviation, d, for each of the candidate arcs is calculated from the last incumbent flow solution. Using Equation 5.4 the arc to be dropped is that arc with the highest value of d. This procedure, (for convenience referred to as the 'Balinski drop phase') is repeated until there are no more relaxed arcs. The normal Sa 'add' and 'swap' phases continue the heuristic. If an improvement to $T_{inc}$ is found in either of these two phases then the procedure carries out an ordinary drop phase as in Sa's original method.

A third improvement to the heuristic is to carry out some of the pre-solution feasibility tests, as were described in Section 4.3. Two tests are particularly useful:

86 (a)

Equation 5.2: Solution Conditions from Balinski's Relaxation

$$t_{rlx} \quad <= \quad T_{opt} \quad <= \quad T_{Bal} \quad <= \quad T_{vmin}$$

Where

$t_{rlx}$ = objective function minimum cost using costs calculated according to Balinski's relaxation

$T_{opt}$ = the true optimal cost

$T_{Bal}$ = the true cost of the Balinski solution found by re-evaluating the flow basis using Equation 5.3

$T_{vmin}$ = the true cost of the variable cost only minimization of the network, where the cost is found by re-evaluating the flow basis using Equation 5.3

Equation 5.3: True Cost of Network Problem, T

$$T = t + \sum_{i,j \in A} (c^{v}_{ij}\, x_{ij} + c^{f}_{ij}\, y_{ij} - c'_{ij})$$

where

$A$ = the set of fixed charge arcs, i,j

$t$ = the minimum cost solution to the NP

$$y_{ij} = \begin{cases} 0 \text{ if } x_{ij} = 0 \\ 1 \text{ if } x_{ij} > 0 \end{cases}$$

$T_{Bal}$ = T if $t = t_{rlx}$

$T_{vmin}$ = T if $t = t_{vmin}$

$t_{vmin}$ = minimum cost of NP using variable costs alone, $c^{v}_{ij}$

86 (c)

Equation 5.4: <u>Deviation from the relaxation, d</u>

$$d = c' x - c^{v} x + c^{f}$$

$$= c^{f} (1 + x / u)$$

x = optimal flow

(Refer to Equation 5.1 for symbol definition)

(a) Comparison of total supply with the total processing capacity available in the candidate problem.

(b) Comparison of global production requirements with process availability for the particular products.

Another test is that used by Gray based upon an upper limit on the total fixed costs which can be allowed in the optimal solution. This limit is calculated using Equation 5.5. If the candidate problem will, if solved, have a greater fixed cost component than $F_{max}$ then the problem is not worth solving since T will be greater than $T_{inc}$. This is because the variable cost component of $T_{inc}$ will always be greater than or equal to $t_{vmin}$, the unrelaxed variable cost minimization of the network.

The number of NPs to be solved in the swap phase is equal to the product of the number of fixed arcs in the basis and the number of fixed arcs out of the basis. The maximum value of this product is $n^2/4$ where n is the number of fixed arcs. It is desirable therefore to avoid entering the swap phase if only small gains to the objective function are likely. This decision can be facilitated by calculating ($S = T_{inc} - t_{rlx}$) which measures the maximal possible degree of suboptimality. By considering S in relationship to other scenarios being evaluated and/or the statistical measurement errors of the model data, the user can make the decision of whether to proceed through the swap phase with the prospect of a worthwhile improvement to $T_{inc}$.

87 (a)

Equation 5.5: Gray's Fixed Cost Limit, $F_{max}$

$$F_{max} = T_{inc} - t_{vmin}$$

where

$T_{inc}$ = best true total cost so far found (the incumbent). An initial value is $T_{Bal}$

## Selection criteria for the heuristic

The criterion for selecting the arc to be dropped in the Balinski drop phase has already been described. For the ordinary drop phase, Sa recommended two criteria : the average production + transportation cost at a factory; or the percent utilization at a factory. For the current formulation, the former is not readily calculable because of the complex network structure with collection, diversion and processing phases. Consequently, the factory with lowest percent utilization (100 x/u) was chosen for dropping.

Sa gave no criterion for selecting the factories to be added or swapped. The criterion used to select an arc to be added was the factory with the lowest fixed cost.

In the swap phase, a table of swap pairs is generated for every combination of factories in and out of the solution found at the end of the add phase. For example, if there are 8 factories out of the solution and 7 factories in the solution then 56 swap combinations exist. Because the procedure returns to the drop phase if a new incumbent is found the order in which the swaps are carried out has a significant impact on solution time through the number of NPs solved. A sort criterion found to be successful in bringing beneficial swaps to the top of the swap table is given in Equation 5.6.

The procedure is described more completely in Appendix 3.

88 (a)

Equation 5.6: <u>Sort Criterion for swap phase, d</u>

$$d = c_o^f - c_1^f + x_o \left(c_o^v - c_1^v\right)$$

<u>where</u>

$c_o^f$ = fixed cost of arc to be dropped

$c_1^f$ = fixed cost of arc to be added

$x_o$ = factory input flow in the incumbent solution for the factory to be dropped

$c_o^v$ = variable cost (or revenue) of factory to be dropped

$c_1^v$ = variable cost (or revenue) of factory to be added

Computational results

Testing of the procedure was carried out using the data presented in Balinski's paper for a standard transportation network involving 8 supply nodes 12 demand nodes and 96 fixed charge transport arcs. Comparative results are shown in Table 5.1. The original Sa method (III) gave a $T_{inc}$ worse than the value found simply by Balinski's relaxation (II). This is likely due to the fact that the transportation problem has a different network structure to the transport plus processing problem for which Sa developed his method. The former has strict demand and supply constraints, whereas Sa's problems only had fixed supplies to handle. The modified method (IV) improved upon Balinski's relaxation (II) but was still some distance away from the best known solution (V). This solution was found using a Branch-and-Bound procedure which had to be terminated due to computing time limitations. There are no reports in the literature of any other solutions to this problem.

Table 5.1 Solutions to Balinski's fixed cost problem

| Method | | Objective Function | |
|---|---|---|---|
| I $T_{vmin}$ | = | 530.70 | variable cost |
| II $T_{Bal}$ | = | 504.55 | truecost from Balinski Relaxation |
| III $T_{inc}(Sa)$ | = | 512.05 | Original Sa method |
| IV $T_{inc}(mod)$ | = | 493.75 | modified Sa method |
| V $T_{opt}$ | = | 482.40 | best known optimal value |
| $t_{rlx}$ | = | 451.05 | Balinski relaxed cost |

A second feature of these experiments is the number of NPs requiring to be evaluated. For methods I and II, just one NP is solved. For method III 1318 NPs were solved with the $T_{inc}$ being found after 187 NPS. For method IV, 1395 NPs were solved but $T_{inc}$ was found after 66 NPs. Further, method III required three cycles of drop, add and swap whilst the modified method found no improvements in the first cycle of the swap phase.

Table 5.2 shows performance characteristics of the NETPLAN model for the month of January, where supply is 68% of total capacity. Test 1 (ALLOPT) shows the results of minimizing just transport and fixed costs, subject to capacity constraints. Although the swap phase was entered three times, the gain was $1,600 compared with the final total cost of $70,800.

In Test 2, product prices and process costs were included for the same months. In this case, the variable cost and revenue components completely outweighted the fixed cost component in the problem, with the result that the solutions were identical for the VAROPT and ALLOPT runs.

Table 5.2: Performance Characteristics of the NETPLAN model

| | Solution time (CPU Seconds) | Network Programs solved | Transport Costs ($k) | Fixed Costs ($k) | Total Costs ($k) | Swap Phase gain ($k) | Maximum suboptimality ($k) |
|---|---|---|---|---|---|---|---|
| Test 1: | | | | | | | |
| ALLOPT | 38.60 | 25 | 21.3 | 49.5 | 70.8 | 1.6 | 7.2 |
| VAROPT | 3.2 | 1 | 15.9 | 72.6 | 88.5 | - | - |
| ratio: | | | | | | | |
| ALLOPT/VAROPT | 12.0 | 25 | 1.34 | 0.68 | 0.80 | - | - |
| Test 2: | | | | | | | |
| ALLOPT | 25.14 | 11 | 23.6 | 55.5 | (1409.3) | 0 | 4.7 |
| VAROPT | 6.35 | 1 | 23.6 | 55.5 | (1409.3) | - | - |
| ratio: | | | | | | | |
| ALLOPT/VAROPT | 3.95 | 11 | 1 | 1 | 1 | - | - |

Test 1: Transport cost and fixed cost minimization, January, capacity utilization = 68%

Test 2: Total revenue optimization, January, capacity utilization 68%

ALLOPT: Variable + fixed cost optimization

VAROPT: Variable cost optimization only. Fixed costs added after optimization

CPU seconds: on IBM 3033

## 5.4 Seasonal effects on factory operation

The total number of factories open for processing in a month depends very much on the milk availability which is extremely seasonal. Thus it is important to determine the number and location of factories to be opened in each month. In determining this information an organisational constraint must be considered which is concerned with labour conditions. Once a factory is opened during the season, it must remain open for a continuous period until its closedown towards the end of the season. In other words, the factory cannot be closed down for a month during the season with workers laid off, and then reopened for a few more months.

This feature is particularly advantageous for the computation of the fixed charge problem described in the previous section. Once a factory has been determined by the heuristic procedure to be included in the solution for a low supply (early season) month, it need no longer be considered by the heuristic until the peak seasonal flow has been attained in October. This results in a considerable reduction in the number of NPs which must be solved in each period. To cope with the declining flow periods a simple device is to reverse the order of solution of the periods. That is, solve in the order May, April, March ... November.

Table 5.3 demonstrates the application of this feature, referred to as "AUTOFIXIN", in solving the model for January where factories opened in the lower supply month of February are kept in the January solution. Solution time is more than halved, although the total cost is not altered to a great extent when "AUTOFIXIN" is used.

This procedure may not give the optimal annual opening and closing sequence. However, the cost of the optimal sequence can be seen to lie in the range:

$$C_f \;<=\; C_o \;<=\; C_a$$

where

$C_f$ = cost given when the "AUTOFIXIN" procedure is not used

$C_o$ = cost of optimal sequence

$C_a$ = cost given when the "AUTOFIXIN" procedure is used

When practical company considerations are also taken into account such as the need for factory maintenance, factory shakedown or labour employment requirements, $C_o$ will generally be driven closer to $C_a$ because of the tighter capacity constraints imposed on the model. These, however, are short-term production planning details and will not be discussed further.

Table 5.3: Performance characteristics of "Autofixin" feature

| | Solution time (CPU seconds) | Network Programs Solved | Transport Costs | Fixed Costs | Total Costs | Swap phase gain | Maximum suboptimality |
|---|---|---|---|---|---|---|---|
| ALLOPT | 38.60 | 25 | 21.3 | 49.5 | 70.8 | 1.6 | 7.2 |
| AUTOFIXIN | 16.44 | 11 | 18.4 | 53.7 | 72.0 | 0 | 6.8 |
| ratio: ALLOPT/ AUTOFIXIN | 2.35 | 2.27 | 1.16 | 0.92 | 0.98 | - | - |

ALLOPT: See Test 1, Table 5.2

AUTOFIXIN: Factories opened in February are kept open in the higher supply month of January.

## 5.5 Annual costs

Once the fixed charge problem has been solved for the twelve monthly planning periods, the year's annual fixed costs are added to the solution for the particular planning scenario. This was described in Section 4.3. Note that it is not appropriate to amortize the annual costs or investment costs into the daily fixed charge, as is common practice. If the amortizing procedure were to be followed, too many factories would be closed down in the off-peak supply periods because of the higher fixed charge relative to variable revenues and costs. It is the peak flow month which determines which factories will be opened during the year, and therefore what annual costs will be incurred. Excessive closing of a factory off-peak will not save any of its annual costs (rates, interest, capital repayment, insurance, administrative or salaried staff, preventive maintenance).

## 5.6 Annual variations and the timing of investment

Due to the varying patterns of milk supply growth and decline over the planning horizon it may be appropriate to solve repeatedly a scenario for a number of years and compare the results with other scenarios. Note that a different scenario might involve delaying the construction of a factory for a number of years. In this way an indication of the timing of construction can be obtained.

The method used to compare different scenarios is the Discounted Cash Flow procedure for mutually exclusive investments, described, for example, in Peters and Timmerhaus (1968). This approach compares the marginal discounted net benefits of the mutually exclusive scenarios. Equation 5.7 gives the criterion for selecting between two projects, and the method is readily generalized to any number of projects. An example of the method is given in Mellalieu (1981, IV).

## 5.7 Identification of feasible set candidates

Section 3.4 compared the infinite set and feasible set approaches to the location problem. It was noted that a major limitation of the feasible set approach is that the optimal site may not be included in the feasible set. This section proposes approaches to aid in identifying a set of candidates which is more likely to contain the optimal.

96 (a)

Equation 5.7: Discounted Cash Flow Criterion for Mutually Exclusive Projects

$$v_{1-2} = -\left(C_1^I - C_2^I \frac{1}{(1+r)^q}\right) + \sum_{p=1}^{P} \frac{1}{(1+r)^p} \left(C_{1p}^A - C_{2p}^A\right)$$

where

$v_{1-2}$ = marginal discounted net benefit between projects 1 and 2

Select project 1 when $v_{1-2} > 0$

$C_j^I$ = investment cost for project j

q = year of investment for project 2 (years from base year = 0)

r = company discount rate

p = year from base year. Planning horizon ends in year P

$C_{jp}^A$ = net annual operating revenue for project j in year p

Note: Costs C in base year terms

Immediately obvious approaches are:

(a) Increase (decrease) capacity in areas where supply is increasing (decreasing).

(b) Replace or increase capacity in centrally sited locations.

(c) Avoid locations on the boundary of the company's operating area.

In order to minimise the impact on transport costs of unforseen variations in product price ratios a less obvious approach is to aim for a balanced product mix throughout the operating area. This is in preference to having centrally located factories producing one product and peripherally located factories producing other products.

The NETPLAN model itself can be used to identify candidates, by employing pattern analysis of transport flow maps. This is described in Chapter 6. Other approaches are:

(a) The uncapacitated transportation model. In this approach the NETPLAN model is used with no factory capacity, process capacity, product demand, process cost or price data. That is: transport costs and milk supply data only. Large discrepancies between existing capacities and the factory flows resulting from this model indicate potential for capacity changes.

This model's results reflect a 'worst case' scenario in which transport costs are very much greater than process costs or product price variations. In the longer term, this model also reflects the possibility that less profitable factories could be upgraded to meet the profitability of other factories with the result that transport minimization becomes the only decision variable for company optimization.

(b) The fixed charge capacitated transhipment model. In this case, the NETPLAN model is used as for the more usual single-period (static) situation. For new factories, the factory fixed charge (Equation 5.8) now includes shift costs (Section 5.2) annual costs and investment outlays ammortized to a daily charge as described in Sa (1968) and Grant (1964). For existing factories (which could be closed down) a measure of the investment outlay for future operation of the factory is the salvage value (Peters et al, 1968) obtainable from the sale of the factory. The salvage value of the factory represents revenue foregone if the factory is allowed to continue in operation.

The results of this model provide the optimal location and capacities of factories when the monthly or yearly variation in milk supply is ignored. Limitations of this approach were mentioned in section 5.5.

## 5.8 Conclusions

A mathematical method for achieving fast, good, sometimes optimal solutions to the daily milk collection and processing problem with non-linear costs has been described. By taking account of the

98 (a)

Equation 5.8: Amortized fixed charge, $C_f$

$$C^f = C^s + (C^A + C^I g) / p$$

where

| | | |
|---|---|---|
| $C^f$ | = | fixed charge amortized on a daily basis |
| $C^s$ | = | daily set-up, close down and shift fixed charges |
| $C^A$ | = | annual fixed operating cost |
| $C^I$ | = | project investment cost |
| p | = | number of production days per year |

and where g = Grant's capital recovery payment factor,

$$g = \frac{r(1 + r)^n}{(1 + r)^n - 1}$$

where

| | | |
|---|---|---|
| r | = | company discount rate |
| n | = | expected factory life, years |

seasonal variation in milk supply, a further improvement in solution time is obtained whilst at the same time more closely modelling the actual management practice of the dairy company. A method for comparing planning scenarios is given which can also be used to identify the timing of investment decisions. Finally, methods for helping generate the feasible set of locations were given.

The results of using the methods identify those projects which dominate over others in terms of net economic benefits. Other strategic factors such as regional balance of production may be required to be compared, and for this reason the DSS aspects of the model have been stressed. The next chapter will identify technical features of the model which support the DSS approach: in particular, high-speed graphic display of transport flow maps and geographic production quantities.

# CHAPTER 6

# TECHNICAL CONFIGURATION AND OPERATION OF THE MODEL

## 6.1 Introduction

The way in which a DSS is used is determined not only by the mathematical and logical features of the model, but also by the hardware configuration and the software interface between the user and the model's logic. This chapter describes these two latter aspects of the model with particular reference to two concerns of the user:

(a) flexibility and ease of use

(b) The opportunity to explore the model in order to become familiar with its predictions, relationships and assumptions.

Following a brief description of the hardware configuration, the design features satisfying these concerns will be described. Namely:

(a) computer generated graphics output.

(b) provision of a variety of small relatively simple tabular reports.

(c) user-oriented interactive command language.

Given the essentailly technical details discussed here, Chapter 7 will describe actual problems to which the model has been applied within the NZCDC.

## 6.2 Hardware configuration

This section describes the equipment used by the NZCDC for running the NETPLAN model and the various subsidiary programmes. The hardware is: (see Figure 6.1).

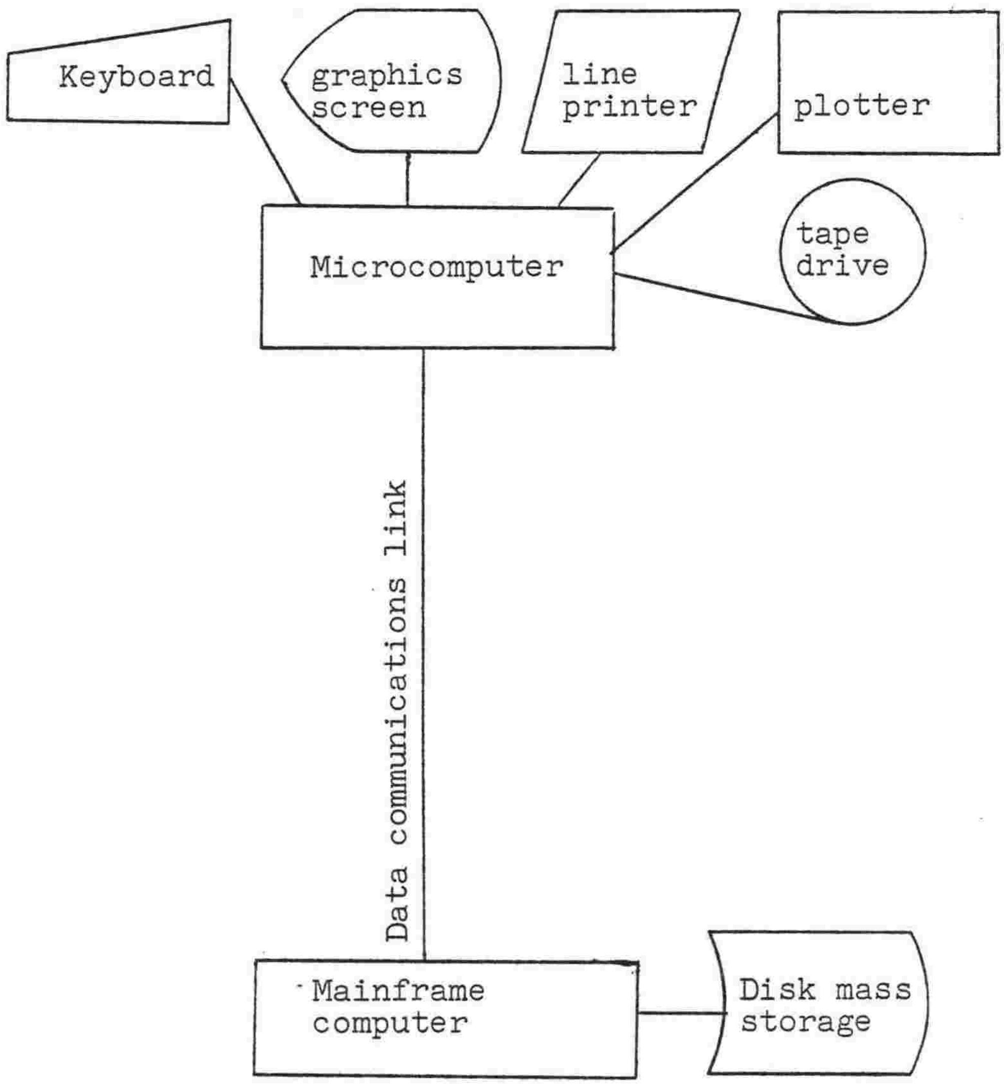
| | |
|---|---|
| Microcomputer: | Tektronix 4051 graphics computing system with keyboard, 32 kbyte memory, 300 kbyte digital cartridge tape drive and high resolution storage scope screen. |
| Plotter: | Tektronix 4662 digital plotter |
| Lineprinter: | Facit two colour line printer with mean printing speed of 120 characters/second |
| Data communications: | modem links over dedicated Post Office lines with a data transfer rate of 120 characters/second. |
| Mainframe computer: | IBM 4341 with 4 Mbytes memory. |

The microcomputer is used to generate output to the plotter and lineprinter in addition to its being connected over the modem link to the mainframe computer. The microcomputer is used for:

- off-line data editing, preparation and checking. For example, the SUPGEN program described in Chapter 4.
- transmitting the off-line prepared data to the mainframe for subsequent use in the NETPLAN models.

101 (a)

FIGURE 6.1 HARDWARE CONFIGURATION



- displaying, printing and plotting the results produced by the models.

The mainframe computer is required for running the main models, and for storing input datasets and output results. Some data editing is carried out, using either installation - supplied editors, or the editor built into NETPLAN.

## 6.3 The Software interface

### Graphics output

Computer-generated graphics output was found to be most useful in providing an overview of the model's solution. In particular, the transport flow maps (Figure 6.2) served both to convince users of the reasonableness of the model, and to aid them in finding better locations for factories. (Section 5.7).

In the figure each supply cell is connected to the factory to which it supplies milk. The thickness of each line is proportional to the quantity transported. The area of each line being the product of distance and flow, is proportional to the transport cost from the supply cell to the factory. Diversion of milk between factories (Phase III, Section 4.3) is indicated by an arrowhead in a flow line.

As an aid to location analysis, various patterns can be seen in the figure such as the "star", the "fan" and the "convoy". The star occurs when a factory is supplied from cells all around it. This suggests the factory is well sited with respect to the

Fig. 6.2 Transport Flow Map


Fig 6.2
Transport Flow Map

102 (a)

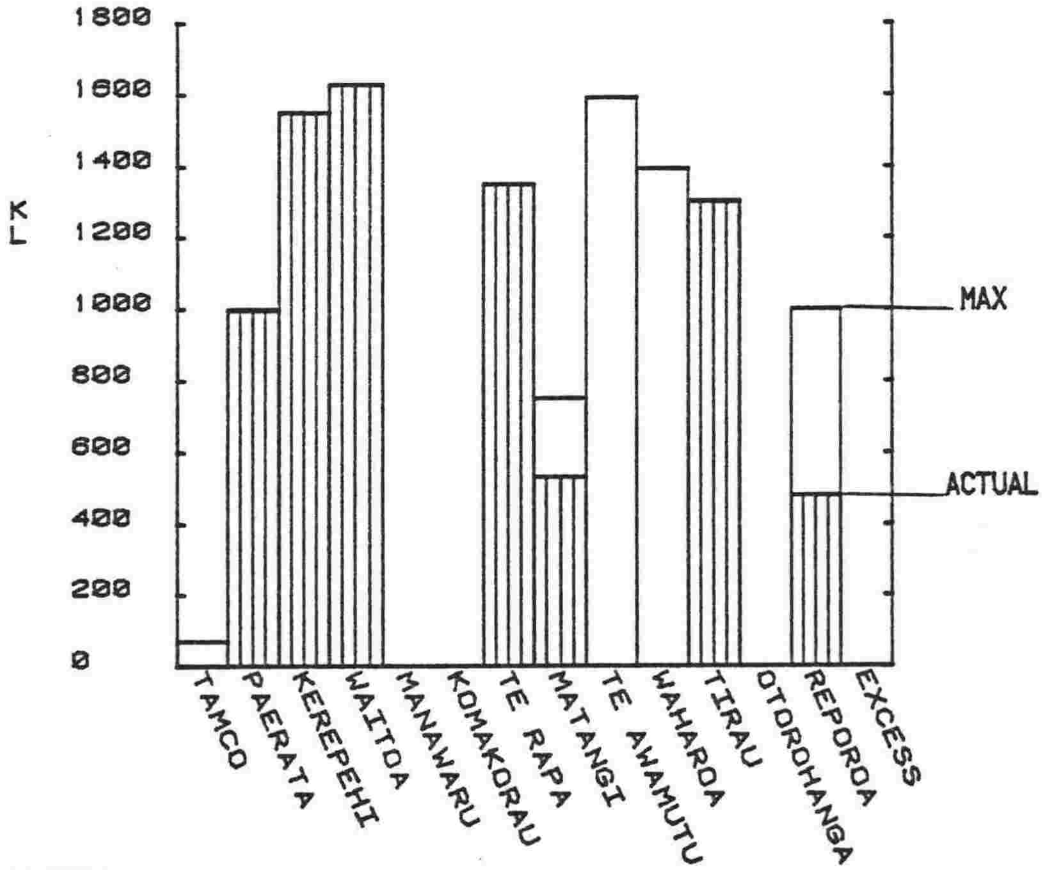
supply. The fan occurs when a factory is supplied from only one side, suggesting a poorly sited factory. If the factory was moved towards the circumference of the fan, a star pattern would begin to develop, indicating a better factory siting.

The convoy is a more complicated version of the fan. It is evidenced by many factory-factory diversions tending towards one factory. Since the diversions can be quite large in volume, a convoy of milk tankers carrying out the diversion can be imagined. The convoy has different implications depending on the availability of surplus production capacity. When there is substantial excess capacity, the convoy merely indicates that milk is being carried to a highly profitable factory (a situation which might be worth investigation by management). When there is little excess capacity the convoy pattern indicates a serious imbalance between the location of supply and the location of processing facilities, and thereby suggests where extra capacity should be made available.

Another use for the transport maps is in data checking. For example if two flow lines cross, this suggests that either the plotting co-ordinates of the cells are incorrect, or more seriously, that the distances between cell and factory for one or both of the cells are incorrect.

Other graphs which proved useful were simple utilization and production bar charts. The utilization charts show maximum and actual capacity used at each factory on a particular day; for a particular factory over a whole year; or for all factories for the whole year. (Figures 6.3 and 6.4).

Fig. 6.3 Daily Company Utilization




WAITOA SEASONAL UTILIZATION

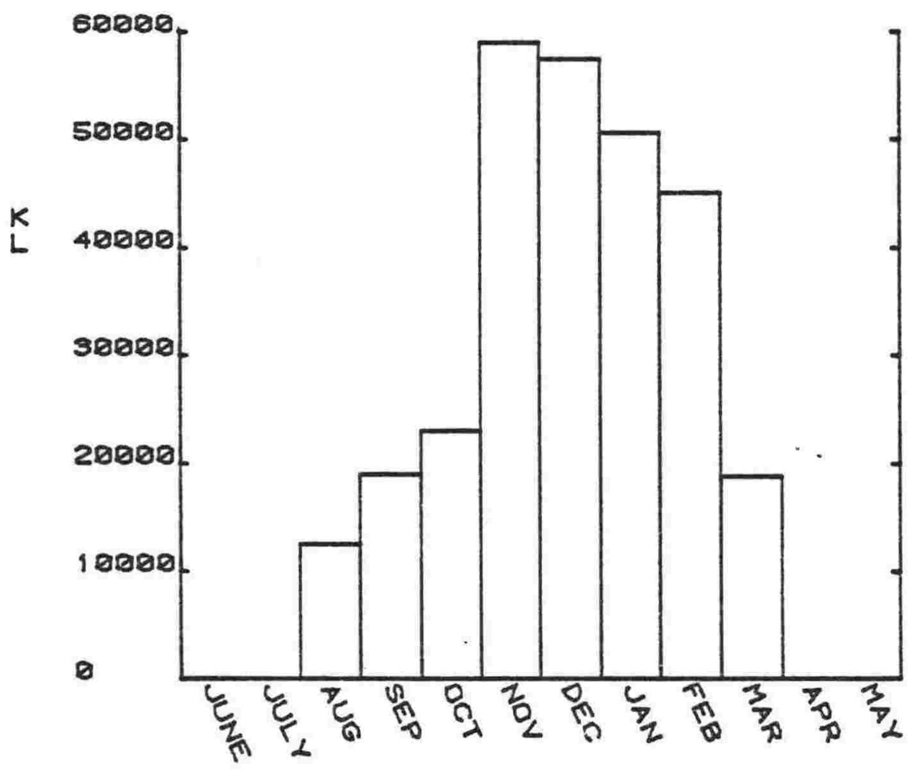
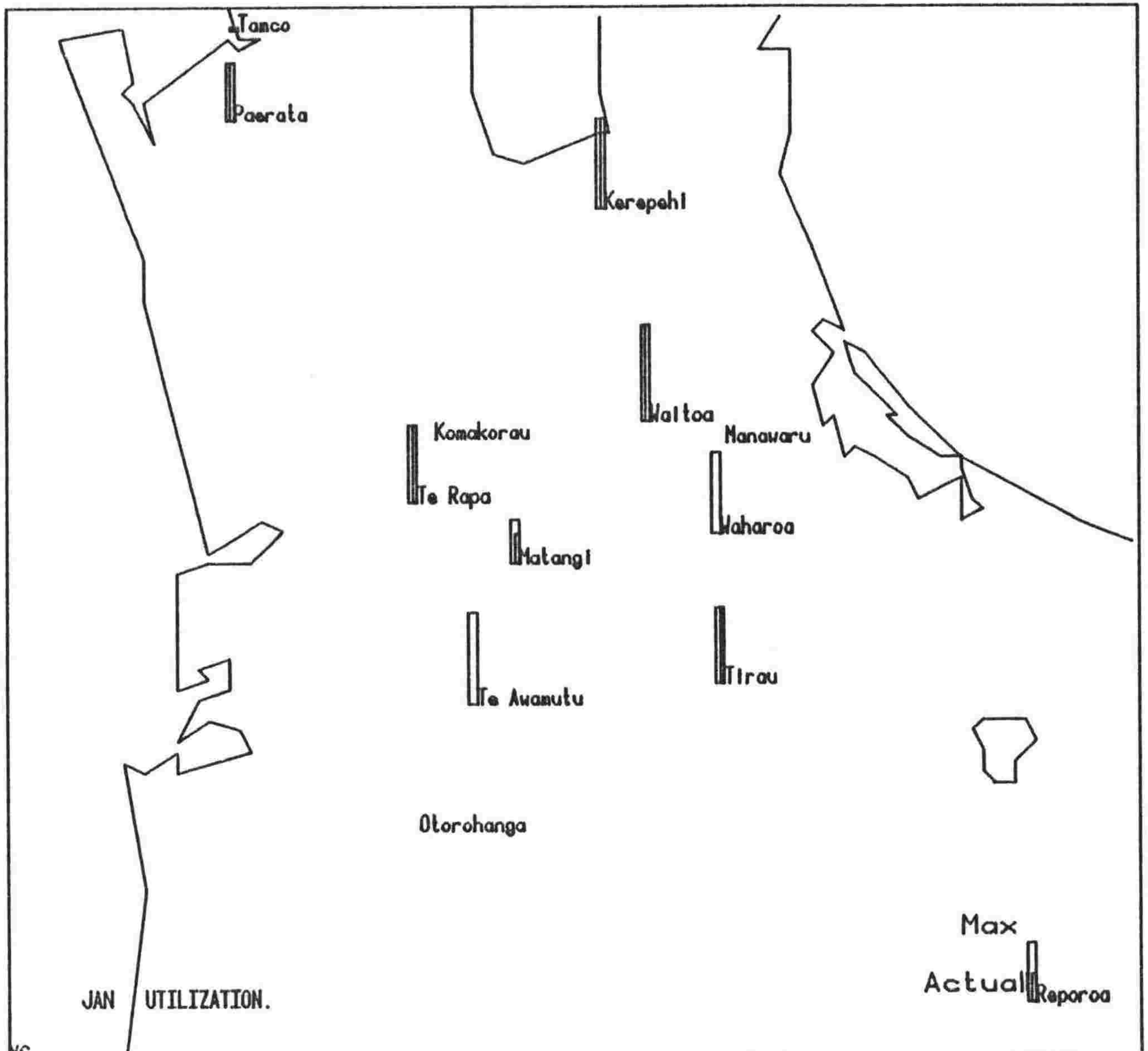



Fig. 6.4 Factory Utilization Throughout Whole Year

103 (b)

Fig. 6.5 Geoplot of Daily Company Utilization



The production charts show where and in what quantities particular products are made.

This same output data can be presented in an alternative form to provide a geographic perspective of the model's results. These 'geoplots' (Figure 6.5) are used in conjunction with the transport flow maps to identify regional production imbalances, or to indicate good locations for subsidiary facilities such as bulk product storage depots.

Reports

Whereas graphic output was found to be most useful for giving a quick, broad overview of the whole model's solution, small tabular reports enhanced the DSS aspect of the model by allowing the user to hone in on specific features of the solution (for example, quantities of cheese made at various factories) (Table 6.1). These small reports were much preferred over "whole solution" reports which often contain data irrelevant to a particular user's field of interest.

Table 6.1: List of reports produced by NETPLAN

| | |
|---|---|
| SUM | Company summary statistics |
| | total profit, transport cost, company utilisation |

(cont...)

| | |
|---|---|
| UTIL | <u>Factory capacity utilisation</u> |
| | maximum capacity and used capacity |
| PLAN | <u>Factory production plans</u> |
| | show process utilisation, quantity and value of products made by each process at a specified factory |
| TRAN | <u>Transport Plans</u> |
| | show which supply cells supply milk to a specified factory, and the cost of transport from each cell |
| TPROD | <u>Total company production</u> |
| | values and quantities of products made by the company as a whole |
| SPROD | <u>Specific production by factories</u> |
| | for a specified product, shows which factory made the product, and the quantity and value produced |
| REV | <u>Revenue and cost analysis</u> |
| | shows the transport costs, production costs and revenues generated by each factory |

(cont...)

SEAS Seasonal utilisation and production

shows how factory utilisation and production varies throughout a 12 month planning period

Note: Computer-generated graphic displays are obtainable from the results produced by UTIL, PLAN, TRAN, TPROD, SPROD and SEAS.

## Command language

The NETPLAN model was designed to cope with both the novice and expert user. Self-documentation of command functions was provided by means of 'HELP' commands. Orderly use of the model was enforced by a hierarchy of command subset levels (a master control level, data editors, solve level and report generation level).

Considerable attention was paid to error detection and recovery, ('crash-proofing') with reference to command entry, data entry and modelling constraints (the latter described in Section 4.3). The expert user was able to save time by using command abbreviations, lists of commands and by avoiding use of the 'HELP' menus. A sample session is shown in Figure 6.6.

## Other features

Through use of the structural parameters (Section 4.3) and self-documenting input datasets the expert user was given complete control over the size and structure of the NETPLAN model. Thus new factories, processes or products could be added to the model without recourse to the model designer. This feature was a major contributor to the model's flexibility, acceptability and 'dynamic validity' referred to in Chapter 3.

106 (a)

Fig. 6.6 Sample Session of NETPLAN Operation

```
Enter MASTER Options, or HELP
HELP

-----------------------------------------------------------------
MASTER NETWORK OPTIONS:-

SUPPLY    Examine or change Supply data
FACTORY   Examine or change Factory data
TRAN      Change Transport costs
TITLE     Enter description for results
SOLVE     Solve network & display results
CONSTRAIN Specify Maximum &/or Minimum production
          of a specific product
NOCON     Discontinue product constraint option
END       END PROGRAM
-----------------------------------------------------------------

Enter MASTER Options, or HELP
:SOLVE

Current SOLVE factors are included:-
Enter SOLVE option, PERIODS, or HELP::HELP

-----------------------------------------------------------------
SOLVE Options. Enter:-

OLD    to recover previously solved basis
SAVE   to save the current flow basis
       (OLD & SAVE speed up the solution in some cases)
ZERO   Reset flow basis to zero
PRICE  Product PRICES included in SOLVE
COST   Process COSTS included
SETUP  Factory SETUP costs deducted from PROFIT
FIXED  Process FIXED costs deducted from PROFIT
NOPRICE, NOCOST, NOSETUP, NOFIXED excludes these factors from SOLVE
VAROPT Carry out optimization using variable factors only
     (eg: PRICES, COSTS & TRANSPORT COSTS)
      SETUP & FIXED COSTS are deducted from PROFIT only
      after the optimization is complete
ALLOPT Carry out optimization using variable & fixed factors.
AUTOFIX The last FLOW basis is used to fix open factories or
       processes in the problem about to be SOLVED.
       This saves solution time when the ALLOPT option is used.
DUMP   Print network formulation & solution onto DUMPOUT file.

PERIOD NAMES ARE:-

 No PERIOD No PERIOD No PERIOD No PERIOD No PERIOD
  1 JUNE    2 JULY    3 AUG     4 SEP     5 OCT
  6 NOV     7 DEC     8 JAN     9 FEB    10 MAR
 11 APR    12 MAY
Enter START & END period for Solution
Enter "END" or <RETURN> to exit
-----------------------------------------------------------------

Current SOLVE factors are included:-

VARIABLE COST OPTIMIZATION ONLY
 : PRICES: PROCESS COSTS: FACTORY SETUP COSTS: PROCESS FIXED COSTS
Enter SOLVE option, PERIODS, or HELP::JAN

ABOUT TO SOLVE FOR JAN
      SUPPLY      MINCAP      MAXCAP      DEMAND
       7906           0       11632           0
SUPPLY OK
```

106 (b)

Fig. 6.6 (cont'd.)

```
   6.46 CPU seconds used for SOLUTION

Current DISPLAY devices are:- PLOTTER SCREEN
REPORT Options, or HELP::HELP

-----------------------------------------------------------------
REPORTS & PLOTS:-

OPTION    RESULT

DISP    Change Output Display Devices
SUM     Summary Statistics
TPROD   Company Product Totals
SPROD   Specific Products by Factories
UTIL    Factory Capacity Utilization
PLAN    Factory Production Plans
TRAN    Transport Collection & Diversion
REV     Factory Costs & Revenues
PNET    Create a SUPPLY data file for a specific product
SEAS    Season's Results so far
AGGREG  Output this period's solution for later aggregation by the NETAG program
ALL     All of the above Reports
END     Exit from Report Phase
-----------------------------------------------------------------

Current DISPLAY devices are:- PLOTTER SCREEN
REPORT Options, or HELP::SUM,TPROD,END

-----------------------------------------------------------------
JAN   PRODUCT MIX COMPARISON
TOTAL PROFIT  $1,409,388.31
TOTAL SUPPLY    7,906 KL
UNIT PROFIT     $178.26  PER  KL
COMPANY UTILIZATION  67.9 %
TRANSPORT COST $23,558.41        49454 KM
-----------------------------------------------------------------

JAN   TOTAL COMPANY PRODUCTION PRODUCT MIX COMPARISON
PRODUCT        PRODUCTION     GROSS VALUE       MINIMUM      MAXIMUM
-----------------------------------------------------------------

SMP:TON              0.00           $0.00
WMP:TON            430.71     $667,598.88
CHEESE:TON         120.29     $228,551.84
R.CAS:TON           43.95     $140,190.91
L.CAS:TON           53.24     $169,840.32
CREAM:TON          502.76     $271,490.24
WHEY:TON          3410.92     $102,327.56
EVAP:TON             0.00           $0.00
-----------------------------------------------------------------
```

106 (c)

Fig. 6.6 (cont'd.)

```
PRODUCT MIX COMPARISON
Enter MASTER Options, or HELP
:TITLE.FACTORY.CON.SOL

TITLE Please                                  V
:PRODUCT MIX COMPARISON: MORE SMP

ENTER FACTORY DATA EDIT COMMANDS, OR HELP
:LIST.MAX.TE RAPA
Factor: MAXCAP
TE RAPA             1350
ENTER FACTORY DATA EDIT COMMANDS, OR HELP
:EDIT..1500

Factor: MAXCAP
TE RAPA             1500
ENTER FACTORY DATA EDIT COMMANDS, OR HELP
:EDIT.PMAX

Factor: PMAXCAP
ENTER FACTORY DATA EDIT COMMANDS, OR HELP
:TE RA.SMP.1500

Factor: PMAXCAP
TE RAPA    SMP                  1500
ENTER FACTORY DATA EDIT COMMANDS, OR HELP
:END

How many PRODUCTS to be CONSTRAINED for
 global company production? ::1
Enter name of PRODUCT for constraint No.    1 ::SMP
Enter MINIMUM allowed production of SMP:TON    ::300
Enter MAXIMUM allowed production
or <RETURN> for MAXIMUM to equal MINIMUM ::500

Current SOLVE factors are included:-
VARIABLE COST OPTIMIZATION ONLY
 : PRICES: PROCESS COSTS: FACTORY SETUP COSTS: PROCESS FIXED COSTS

Enter SOLVE option, PERIODS, or HELP::OLD.JAN
CONSTRAINED PRODUCTION
PRODUCT                      MIN               MAX          POSSIBLE
SMP:TON                  300.0000          500.0000         499.7588
       SUPPLY       MINCAP        MAXCAP          DEMAND
         7906            0         11782            3477
SUPPLY OK
YIELD OF CONSTRAINED PRODUCTS
PRODUCT    TOTAL YIELD    MEAN YIELD
SMP:TON          300.0069          0.0862
NOTE:  2 Iterations required

    3.37 CPU seconds used for SOLUTION

Current DISPLAY devices are:- PLOTTER SCREEN
REPORT Options, or HELP::SUM.TP.END

-----------------------------------------------------------------
JAN   PRODUCT MIX COMPARISON: MORE SMP
TOTAL PROFIT  $1,320,088.12
TOTAL SUPPLY    7,906 KL
UNIT PROFIT     $166.97  PER  KL
COMPANY UTILIZATION  67.1 %
TRANSPORT COST $26,579.11        56285 KM
-----------------------------------------------------------------

JAN   TOTAL COMPANY PRODUCTION PRODUCT MIX COMPARISON: MORE SMP
PRODUCT          PRODUCTION       GROSS VALUE       MINIMUM       MAXIMUM
-----------------------------------------------------------------
SMP:TON             300.01      $330,007.36        300.00        500.00
WMP:TON             386.97      $599,802.08
CHEESE:TON          120.29      $228,551.84
R.CAS:TON             0.00            $0.00
L.CAS:TON             5.00       $15,957.97
CREAM:TON           535.32      $289,070.72
WHEY:TON           1035.98       $31,079.37
EVAP:TON              0.00            $0.00
-----------------------------------------------------------------
```

## 6.4 Operation of the model

The 'hands on' user of the model is a 'staff analyst' to use the terminology proposed by Alter (1980). In this role the staff analyst acts as the intermediary between the model and the many senior managers (clients) requiring an analysis by the model. The analyst has control and responsibilty for maintaining the datasets used by the model; formulating the manner in which the model can be used to meet a specific request; carrying out the model runs; and presenting and discussing the results with the client.

If many data changes are required these would normally be done on the microcomputer and then transferred to the mainframe thus saving mainframe connection charges. Otherwise, direct use of the mainframe programs begins.

During a run of NETPLAN or NETAG summary reports and plots are produced whilst larger reports are output to the mainframe's disk datasets. At the end of a run, the disk datasets can be printed at leisure on the lineprinter via the microcomputer.

Should the staff analyst be interupted, the state of the model's data may be 'frozen' for restarting at a later time. Considerable flexibility in the use of the configuration is possible: for example, graphs may be displayed on the microcomputer screen and then stored on magnetic tape for later off-line plotting.

In some cases, once a particular run has been set up, the client is invited to stand by and propose variations in order to determine the model's sensitivity to changes in the problem's parameters. In this approach fast, interactive use of the model was found to be vital. For many applications, however, NETPLAN is run on an 'as required' basis with the whole process of analysis, model preparation and operation carried out over a few days. Nevertheless, the interactive features of the model have proved especially useful to the staff analyst user in terms of providing:

(a) continuity of thought whilst carrying out an analysis.

(b) consideration of wider range of alternatives and the ability to fine-tune the analysis.

(c) reduction in time required to debug a model (in terms of model feasibility rather than program code errors.) (Compare with comments of Alter).

Although an initial design goal was that decision makers should be able to have direct 'hands on' use of NETPLAN, this has not been achieved. In retrospect the goal was not realistic because of the amount of time and effort required to become familiar with both the model's assumptions and the task of operating an interactive computing facility. The large number of people making use of NETPLAN analyses further recommended the use of a staff analyst who could efficiently co-ordinate, translate, and action their requests. This approach is confirmed by Alter who concluded in his extensive evaluation of Decision Support Systems:

"It is conceivable that nonexperts should be discouraged rather than encouraged to use on-line systems without the help of expert intermediaries".

## 6.5 Conclusions

This chapter has described and demonstrated the practical features of the model which have contributed to its effective use within a company planning role. These features included the hardware configuration and the software interface between the user and the model. The flexible manner in which the model as a whole can be operated has also been stressed. The next chapter will describe how the model has been used to support the company's decision making by reference to specific cases.

# CHAPTER 7

# IMPLEMENTATION AND APPLICATION AS A DECISION SUPPORT SYSTEM

## 7.1 Introduction

Considerable attention was paid to the provision of computer-aided support for the company's decision makers. This chapter describes how the model was implemented in the company in order to maximise the likelihood of its successful application. Part of the approach involved the progression from a simpler model to the current model and these developments are described briefly. Indications are given as to the acceptance of the model by the company. Finally, details are given concerning some of the planning problems to which the model has been applied.

## 7.2 Implementation

Hammond (1974) provided a valuable approach to the implementation of corporate models, and many of his proposals were adopted in the current study. After the usual modelling procedures of formulation, data collection, debugging and validation, he notes that:

"Users must be educated, and the model must gain acceptance. Most of the model's users will have little experience in formal techniques, and their knowledge and background must be augmented. Even more importantly, they must be filled in on the specifics of the model in question."

Two types of user were identified within the company - the 'hands on' user, or 'staff analyst' to user Alter's term, and the more senior company managers. With the latter, informal meetings and review seminars were presented to ensure "... understanding of the model's capabilities and limitations so that its output can be creatively and intelligently used in the planning process" (Hammond). Considerably more effort, however, was spent on augmenting the staff analyst's capabilities. This included hands on training in the use of the computer facilities and the model; provision of the interactive and 'HELP' features of the model; a user manual (Mellalieu, 1982, I) and technical reports on specific features or applications of the model (fixed cost heuristics, network formulation, validation tests (Mellalieu, 1981, I, II, III). To support the staff analyst in her explanation of the model to senior managers, a simplified outline guide to the model was prepared. A report outlining the overall context of location planning was written (Mellalieu, 1981, IV) which covered such aspects of long range planning as cost measurement, intangible and technical assessments and DCF techniques.

## 7.3 Model development

The model described in chapters 4, 5 and 6 developed over the research period from a series of simpler models as recommended by Hammond and Fick and Sprague (1980). For example, the first model had fewer netcells, no diversion distances, or fixed cost minimisation, and used the centre of gravity distance estimation method. This model was useful in identifying the importance of transport minimisation and demonstrated the potential of an on line interactive computer-based planning model.

The expansion of the model to its current form arose out of the desire to model more completely and more accurately the company's operations once familiarity and acceptability by the company of the earlier model was achieved. A second reason was that the simpler models identified which aspects of the model were most sensitive and therefore required more accurate formulation or data. A third reason was to widen the flexibility of the model to cope with new problems. For example, the first model was not detailed enough to enable evaluation of the benefits of putting in a pipeline over a river to a group of farms, rather than collecting by tanker. This kind of analysis became possible with the more detailed and accurate modelling of collection distances in later models.

## 7.4 Model acceptance

Acceptance and support of the model has been very good, as evidenced by the company's purchase of advanced graphics equipment, payment for computing costs and, most importantly, staff support. The need for such a model was well-appreciated by the company, but effective use of the model could only have come from the willingness and ability of the staff analyst to use and apply the model to the various situations which arose. A further indicator of acceptance is the continued effort by the company to increase the model's size and accuracy as mentioned above.

Convincing the decision-makers of the validity of the model's results has not been a serious problem. Reasons for this include the logical nature and network formulation of the model; the graphics output which contributes to explaining the model's complete solution; the thorough understanding of the model by the staff analyst who could discuss the reasoning of the model with the decision-maker; and the care taken over model validation and documentation.

We turn now to specific applications of the model by the NZCDC.

## 7.5 Applications of the model

### Location Studies

In 1978-79, the company was faced with the need to replace outdated factories at Matamata, Gordonton, Waitakaruru and Waihi (the latter built in the 1950s), and the early version of the NETPLAN model was used to evaluate the transport cost implications of a number of alternative investment proposals. These model runs used transport costs, peak milk supply and daily factory capacities as the constraints. Capital costs were then added to the expected transport costs arising from the various proposals.

The feasible set of locations included Tamco, Paerata, Waitakaruru, Kerepehi, Waihi, Komakorau, Gordonton, Te Rapa, Matangi, Te Aroha West, Manawaru, Waitoa, Waharoa, Matamata, Putaruru, Reporoa and Te Awamutu. These 17 sites included existing and proposed sites.

At the time of the study, the company's milk supply was expected to decrease in the Central Waikato area but increase in the South Waikato area. In view of the need to replace existing capacity, the best proposal involved a combination of capacity expansion in the north and eastern areas, (at Kerepehi and Waitoa) and construction of a new plant in the south west at Putaruru. Table 7.1 shows the capital costs and capacities of the plants which were actually constructed over the following 3 years. Rather than construct a plant at Putaruru, the company hedged against the uncertainty of the increasing supply in the south, and constructed the plant at Tirau, some 9 km to the north.

Table 7.1: Capital Costs of Recent Dairy Factory Investments

| Location | Product | Capital Cost ($m) | Maximum Capacity (kl/day) | Capital Cost per kilolitre ($/kl) |
|---|---|---|---|---|
| Tirau | casein | 37 | 1800 | 20500 |
| Kerepehi | cheese | 16 | 500 | 32000 |
| Waitoa | cheese | 15 | 500 | 30000 |
| Waitoa | wholemilk powder, baby foods | 31 | 1800 | 17200 |
| Total | | 99 | 4600 | 21500 |

Source: NZDE, (1980, II), Tichbon (1981)

To demonstrate the impact of this study, Figure 7.1 compares the October transport flow map with and without the Tirau factory (in the latter case, the capacities of the Te Awamutu and Waharoa factories were both increased by 900 kl). The Tirau site saves 5,000 km/day or 11.5% of the total company distance travelled. Over ten years this is a saving of approximately 10 million kilometres (considering seasonal variations) or $7 million (1978 terms) in direct operating costs.

a) Tirau open b) Tirau not open


Fig. 7.1 Comparison of Transport Flow Maps for Tirau Location Study

115(a)

Because only transport costs were considered in this example, the savings form an upper limit. Since the new factory is more profitable than those already in existence, milk may be drawn to Tirau away from other factories, thereby increasing transport costs. This effect (which can now be evaluated by NETPLAN through incorporation of product prices and costs etc.) supports the decision to locate Tirau closer to the other factories than is suggested by simple transport minimisation.

### Smoothing the Flush

A major problem facing the dairy company over recent years has been the steady rise in the flush volume of milk supplied (see Chapter 2, Figure 2.1). Statistical analysis suggested that the cause of this rise was due to:

- increases in the number of cows.
- increases in the flush milk supplied per cow.

The increase in flush milk per cow was found to be related to better than normal pasture growth in recent years (based on the days of soil moisture deficit technique developed by Maunder (1979)), and a general growth in productivity per cow (Equations 7.1 and 7.2).

Equation 7.1: Daily Peak Milk Flow Per Cow

$P_t = -522.16 + 0.0322\ f_{t-1} + 0.2693\ t$

where

P = peak milk flow in litres per cow

f = total annual milkfat produced per cow, kilogram/cow

t = calendar year

and

$r^2 = 92\%$

df = 10

Equation 7.2: Annual Milkfat Per Cow

$f_t = 162.51 - 1.057\ S_{Feb} - 1.198\ S_{Dec}$

where

$S_{Feb}$ = days of soil moisture deficit in the month of February at Ruakura

$r^2$ = 88%

df = 10

No further analysis was carried out to determine the causes of the increase in cow productivity, but industry sources have suggested genetic improvement, changes in cow breed and changes in farm management practices which have matched more precisely pasture growth with the feed requirements of the cows.

The capital cost required to enable processing of the extra milk at the flush is derived in Table 7.1 where the capital cost of recent company investments is divided by the daily maximum capacity of the plant. Rather than using the least cost of $17,200/kl it is suggested that the figure of $21,500/kl averaged over all investments is more reasonable. To choose the lower figure would imply that all new investments should be wholemilk powder factories which is not satisfactory over the long term with respect to product mix and product pricing conditions. To this capital cost the non-processing cost overheads should be added, but these were found to represent only 6.3% of total costs, and so were ignored from the analysis.

The NETPLAN model was used to determine the marginal net revenue per kilolitre of milk supplied in each month. The purpose of this was to quantify the benefit of the product diversification that can occur only in non-flush production months. The marginal revenue was found by solving the variable revenue company moel for each month, and then increasing the overall supply by a small percentage. The change in net revenue was then divided by the change in supply.

The difference in marginal revenue between a kilolitre of milk arriving off peak and at the flush was calculated and these figures are shown in Table 7.2. This table shows only the benefit of shifting one kilolitre on one day from the flush to another period. It is more reasonable to suppose that a whole month's production would be shifted so that increasing the marginal benefit by a factor of 30 is required. For example, shifting a kilolitre to August would result in a benefit of $750. This product diversification benefit, however, is relatively small compared with the capital savings which would accrue from off peak production. Further, if the process of peak shifting was continued to the extreme the supply curve would become rectangular and there would be no marginal benefit at all from off peak supply.

Table 7.2: Value of Diverting 1 Kilolitre of Milk From Peak to Off Peak Processing

| Month | Increase in Net Variable Revenue ($ per kl) |
|---|---|
| June | 66 |
| July | 68 |
| August | 25 |
| September | 1.80 |
| October | 0 |
| November | 1.70 |
| December | 3.80 |
| January | 22 |
| February | 25 |
| March | 27 |
| April | 41 |
| May | 45 |

Note: Using current (1982) international product prices.

Based on industry judgements on the likely increases in cow numbers and cow productivity described in Equations 7.1 and 7.2, the long run annual increase in the flush volume was estimated to be 1.32% (BBA, 1981, II). For the NZCDC, a one kilolitre increase in flush milk requires this growth rate to be applied to 33 farms. Thus the maximum incentive which could be paid per farm to encourage an alteration in the supply pattern is $651.50 per year based on the capital cost per kilolitre-derived in Table 7.1.

There are many alternative ways in which the shifting of the peak could be managed (and therefore the basis on which the incentive is paid) and these are currently being investigated by the company. For example, the shift could be applied evenly over all farms, or a few farms could be selected who would make dramatic changes to their production cycles. The location of farms may also be important. Farms in the warmer north could be encouraged to produce earlier, whilst those in the south could produce later, thereby exaggerating the existing variation in supply patterns.

### An insurance problem

One cause of temporary factory closure is the explosion of milk powder and air mixtures. Although an infrequent event (approximately once every two years) NETPLAN was used to determine the loss of profit arising out of the need to divert milk away to more remote or less profitable factories. This involved closing each factory down one at a time at critical points of the annual production cycle. The results enabled the company to compare the costs of insurance with the costs of implementing improved process control equipment.

### Takeovers and mergers

The impact of merging with smaller dairy companies in the region has been determined by estimating supply and capacities of the target companies and incorporating the data into a NETPLAN model. For reasons of commercial confidentiality these studies cannot be discussed in greater detail, but the basic methodology is described in Chapter 8.

Product price decisions

Sometimes the Dairy Board has a sudden increased requirement for a particular product, and negotiations take place to determine an acceptable price. NETPLAN can be used to carry out a quick analysis to find the minimum acceptable price, using the global product demand feature of the model, in addition to exploring other production ramifications of the contract.

Cross-validation with the Production Planning LP

A number of experiments were carried out to compare the company's production planning LP (Chapter 3) with NETPLAN. An early version of the NETPLAN model was used, (with 66 cells and the COG distance method) to solve the production planning schedule for mid-September 1980. Out of a company net realization of $939,000 (as determined by the LP) there was a $3,000 difference (0.3%) which was attributed to:

- differences in the modelling of transport
- differences in byproduct selling prices (See Chapter 4)
- differences in the way yields are calculated.

Transport costs and distances were compared with actual operational results and the LP results for the same period. One run used factory minimum capacties set to the quantity of milk actually processed by the company (Run I) and Run II used minimum capacities set equal to the factory flow allocated by the LP. Table 7.3 shows the results, where it is noted that the LP model over predicted distance by 48% and the NETPLAN model over predicted by 20% (Run I).

Table 7.3: Transport Comparison of Two Planning Models

| | Actual | NETPLAN Run I | NETPLAN Run II | LP |
|---|---|---|---|---|
| Milk processed, kl | 8242 | 8244 | 8244 | 8225 |
| distance, km | 36162 | 43469 | 44428 | 53700 |
| cost, $ | - | 19182 | 19606 | 23714 |

Note: LP distance calculated from mean company transport cost and load data.

This study led to the development of the expected travelling salesman distances method described in Chapter 4 which gives much more accurate distance prediction (Appendix 1).

Remote farm milk collection

The New Zealand Dairy Board wished to evaluate the possibility of charging remotely located dairy farms a milk collection fee (the current payout method was such that all farms in effect paid the same cost per kilolitre of milk supplied). The NETPLAN model was required to produce the distribution of tanker trip lengths, assuming that farms supplied the closest factory with available capacity. This type of report was not produced by the model, but a program for the micro-computer was quickly developed to derive the required results from the transport plan reports (Chapter 6, Table 6.1).

The number of tanker trips, t, required to collect milk from a net cell was calculated from $t=v/l$ where $v$ = volume and $l$ = average collection load size (in kilolitres). The distance per trip, d was calculated from d = T/(tc) where T = total collection cost from netcell, and c = transport cost per kilomtre. The distribution of trip distances d was then calculated and is given in Table 7.4 for three periods. Due account was taken of the regional variation in load size and transport costs. Table 7.5 compares the results of this analysis with the available data from company operations. Differences are attributed to use of a distance minimising model compared with actual operation where product prices and costs would have affected the transport pattern. Excess town milk supply was also excluded from the analysis, which accounts for some of the variation in mean trip length.

The distance suggested as the level at which the remote collection fee should be charged was 60 kilometres. From Table 7.4 it can be calculated that for October 25% of farms are this distance or greater from the closest available factory (16% for August and 25% for January).

The cost of collecting milk from a farm 60 km distance is approximately $4.50/kl to $5.50/kl depending on tanker capacity. In comparison with the marginal benefit of processing this milk (see previous section on 'smoothing the flush'), this transport cost is very small and the proposal was abandoned, because of the possibility of a negative impact on total milk supply. Adoption of such a proposal could also have inhibited the rational location and investment of new factories, since farmers in an area threatened with closure of a redundant factory without the possibility of a replacement in their locality might find themselves liable to pay the remote collection fee.

Table 7.4: Trip Length Distributions

| Trip Length (km) | Proportion of Trips (%) | | |
|---|---|---|---|
| | August | October | January |
| 0 < 10 | 0 | 2.7 | 0.9 |
| 10 < 20 | 22.3 | 26.7 | 25.4 |
| 20 < 30 | 22.0 | 18.1 | 19.1 |
| 30 < 40 | 19.0 | 12.9 | 13.7 |
| 40 < 50 | 14.8 | 10.0 | 10.1 |
| 50 < 60 | 5.5 | 4.9 | 5.9 |
| 60 < 70 | 4.5 | 8.7 | 6.5 |
| 70 < 80 | 2.8 | 4.6 | 5.9 |
| 80 < 90 | 3.5 | 1.1 | 1.6 |
| 90 < 100 | 0.7 | 0.7 | 1.9 |
| 100 < 110 | 0.0 | 1.6 | 0.6 |
| 110 and over | 4.8 | 8.1 | 9.3 |
| loads (n) | 449.0 | 870.0 | 679.0 |
| mean (km/trip) | 40.9 | 42.7 | 44.0 |
| mode (km/trip) | 20+/-10 | 15+/-5 | 15+/-5 |

Table 7.5: Comparison of model results with actual operational results (October)

| | Model* | 1979-80 | 1980-81 |
|---|---|---|---|
| Supply (kl) | 9842 | 9165 | 10431 |
| Distance (km) | 37125 | 40694 | 39483 |
| Trips | 870 | 1058 | 1069 |
| Mean (km/trip) | 42.7 | 38.5 | 36.9 |

*Town milk supply surplus excluded in the model, but included in actual operational results.

NETPLAN has had various indirect effects on improving the company's planning. For example, encouraging the development of better data collection systems. Computer graphics have extended into other areas in the company such as factory floor production monitoring and for supplementing the output results from the production LP. The major impact, however, has been to enable and to encourage the company's planners to consider the broader, company wide impacts of their decisions.

## 7.6 Conclusions

The Decision Support System implemented in the NZCDC is used to support top-management decision making in a wide range of applications in addition to the location planning problem considered at the outset.

The DSS evolved over a number of years in response to both new planning requirements and the desire to improve the accuracy of results. The resulting DSS comprises:

- A methodological framework for carrying out long-range planning studies which emphasises a standard analytical approach, standardised data definitions and the integration of decision-makers' requirements with the analytical approach.

- A mathematical model whose logic and data has been well tested and validated under a range of applications.

- An interactive graphics-oriented computer configuration which permits the model to be used in a timely and effective manner.

- A staff analyst based within the company who has responsibility for interpreting decision-makers' ideas, analysing them, (as appropriate) using the model, and communicating the results to the decision-makers. The analyst works within the planning framework and has complete responsibility and control over updating the model's data.

- A team of decision-makers who have an understanding of the model's framework such that they can take advantage of it for their planning requirements.

The DSS has a wide degree of acceptability as a complement to the company's decision making processes. The wide range of applications supports this observation and highlights the overall flexibility of the modelling and implementation approaches.

The next chapter describes a more detailed application of the model to industry level strategic decision making, in which location planning formed a less important aspect.

# CHAPTER 8

# USE OF NETPLAN TO INVESTIGATE THE BENEFITS OF INDUSTRY RESTRUCTURING IN THE SOUTH AUCKLAND AND BAY OF PLENTY DAIRY INDUSTRY

## 8.1 Introduction

This chapter describes how NETPLAN was used to contribute to a large strategic planning exercise concerned with restructing the dairy industry in the South Auckland and Bay of Plenty dairying regions.

NETPLAN was used not so much to aid in factory location, but rather to indicate transport cost and processing cost savings attributable to various reorganisations of the industry. Consequently, a number of simplifications in the use of NETPLAN were made, and these are discussed.

The formulation of the NETPLAN sub models for this study are described and brief results are given.

## 8.2 Reasons for the Study

In 1980, the New Zealand Dairy Board outlined its development strategy up to 1990 (Mehrtens, 1980) with specific reference to the industry's production capability at that time. In particular, the plan called for greatly increased production of cheese, relative to current levels of production in butter, casein and milk powders.

Following the publishing of the strategy, the South Auckland and Bay of Plenty Dairy Companies Association, an organisation representing the 11 dairy companies in the region, decided to commission a study to determine how the region could best meet the Dairy Board's objectives.

The objective of the study was:

"To maximise returns to producers (farmers) by investigating the degree of restructuring necessary, if any, to meet the requirements of the New Zealand Dairy Board for the provision of adequate manufacturing capacity in terms of product mix capabilities and within the confines of finance available." (BBA, 1981, I)

Some of the issues which gave impetus to the need for a broad ranging strategic study of the whole region were:

(a) The large capital expenditures required over the 10 year period. The Dairy Board estimated these to be of the order of $300 million for the region. In addition to the reasons described in Chapter 2, the capital expenditure was required to enable a greater diversity of products to be manufactured, as indicated by the Dairy Board strategy.

(b) Competition for milk supply. Because some companies competed for milk supply in the same area, this was thought to increase milk collection costs and give rise to individual companies having excess capacity. This was because companies anticipate a greater supply than they subsequently receive.

(c) Inability of small companies to diversify production. The smaller companies typically had just one factory producing butter and either milk powders or caseins. The small size of these companies would not permit them to commit capital to a cheese factory, unless the smaller companies could merge into a larger organisation and thereby share the expense.

(d) Increased production flexibility. If all the companies amalgamated, then this would reduce capital requirements by allowing milk to be diverted from any farm to any factory whose product was in demand at the best price.

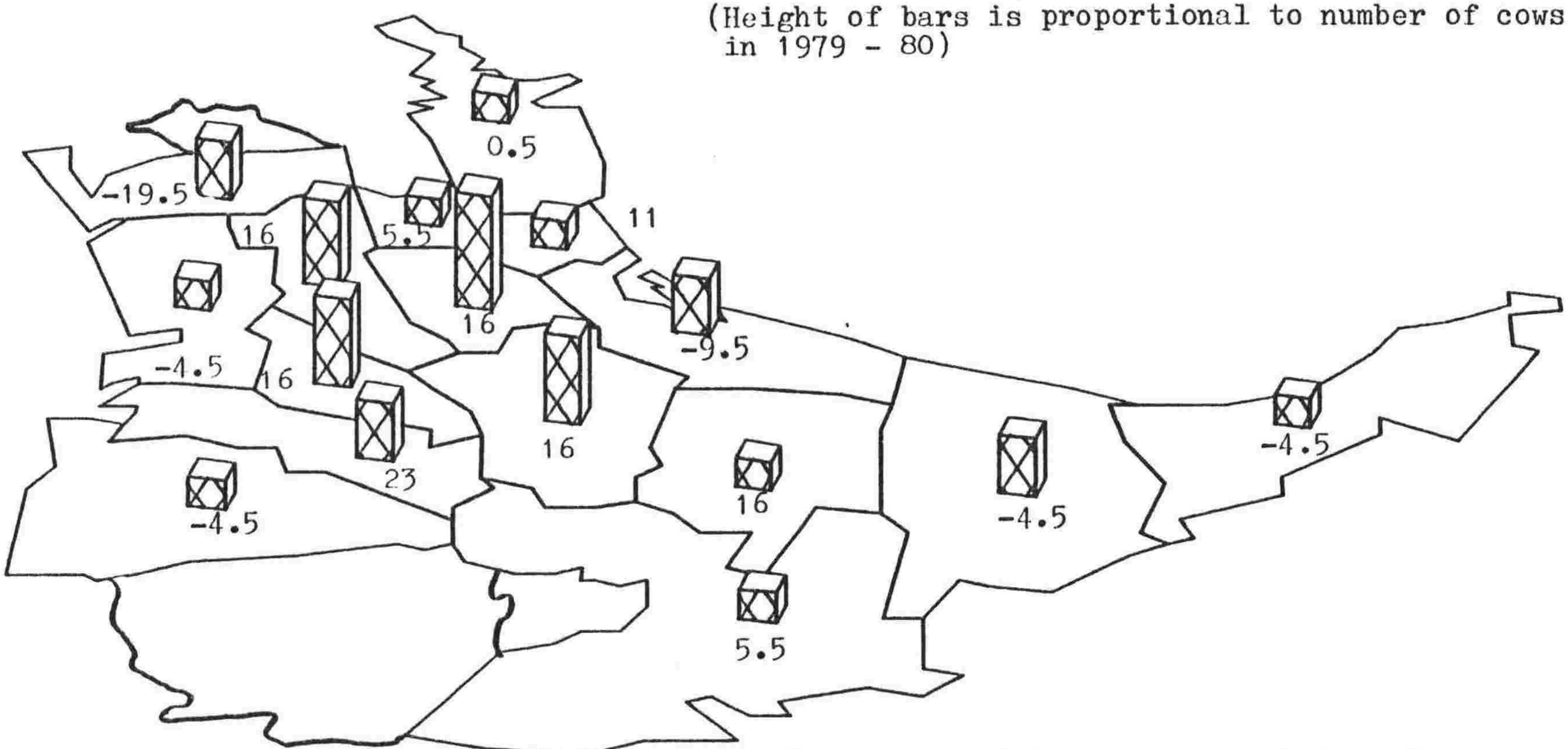
## 8.3 Features of the Study Region

Table 8.1 shows summary statistics for the region. The region is also characterised by a wide variation in the density of milk production due to competing land use and productivity, as shown in Figure 8.1. The figure also indicates a wide range of expected milk production growth rates. The central counties are expected to have an increase in dairy production of 16% over the 10 years to 1990, whereas in the areas close to Auckland city, production is expected to decline by 19.5% over the same period (BBA, 1981, II).

# SOUTH AUCKLAND COWS IN MILK

(Figures show %increase in milk production expected from 1979 to 1990)

(Height of bars is proportional to number of cows in 1979 - 80)




Source: NZ Dairy Board Cow Census
Barr Burgess Associates, 1981 (II)

Fig. 8.1 South Auckland Cows in Milk

Table 8.1: Summary Statistics for the South Auckland and Bay of Plenty Dairying Region

| | |
|---|---|
| Number of companies | 11 |
| Total number of farms (suppliers) | 7065 |
| Company sizes (suppliers/company) | |
| : largest (NZCDC) | 4300 |
| : smallest | 18 |
| : 8 companies have 200-500 suppliers | |
| Total milkfat processed (1980) tonnes | 164000 |
| Annual turnover (1980) | \$500 million |
| Total number of cows (1979) | 1033000 |
| Peak daily milk supply (1980-81), kilolitres | 16844 |
| Area of region in dairying, $km^2$ | 15000 |

## 8.4 Carrying Out the Study

The dairy companies association selected by tender a team of consultants from Barr Burgess Associates Ltd. One of the association's members, the New Zealand Co-operative Dairy Co Ltd, recommended the modification and use of the NETPLAN model, because of their satisfaction with the model. As a result, part of the tender specification required that the applicability of NETPLAN to the study's objectives be examined and compared with alternatives.

The consultants decided that NETPLAN's interactive operation and flexibility in terms of simulating alternative formations of the company organisations in the region was a most favourable feature. In particular, the detailed representation of supply and transport relationships favored the model over the other models described in Chapter 3 (BBA, 1981, I).

Having made the choice of NETPLAN advice was given in the formulation and operation of the model with respect to data collection, data aggregation and the general approach to investigating the economic features of various organisational structures. Some training of the consultants in the use of the NETPLAN model was also carried out.

## 8.5 The Alternative Organisational Strategies

Following discussions with all the dairy companies, four alternative organisational strategies were chosen for analysis. These were:

(a) Status Quo - where the 11 companies were left in their 1980 situation.

(b) Independants Combine - where all the smaller companies would combine into two larger companies, one based in the Waikato (seven companies) and the other in the Bay of Plenty (three companies). NZCDC would stay intact as a separate company.

(c) Single Company - where all the companies amalgamate.

(d) Regional Companies - where a complete restructuring of supply and company ownership was proposed. The restructuring involved dividing up the whole region into six areas, with all milk supply being processed by one company in that area. Each company would have one or more factory sites.

## 8.6 Analytical Approach

For each of the strategies, the analytical approach adopted was:

(a) Determine the 1980 and 1990 plant capacities. For 1980 this was identical to the currently existing situation. For 1990 this involved surveying the capital expenditures in facility upgrading which were likely to occur over the planning period or the particular strategy. For the regional grouping and single company strategies, this involved using NETPLAN to test variations on the location of extra facilities to determine their optimal location in 1990. The best sub-options for 1990 were subsequently used as the basis for comparisons between the strategies.

(b) Set up the NETPLAN network distance, supply and factory data files for each of the strategies, and use NETPLAN to determine the variable transport and processing costs for each strategy in 1980 and 1990. These costs were then added to the investment costs associated with the strategy. Product prices were not included in the model. Instead total global annual production requirements were established reflecting Dairy Board production requirements.

(c) Using predictions of milk supply, and product market requirements (BBA, 1981, II) annual costs for the intervening years were interpolated from the 1980 and 1990 results. From this data, the total costs of the strategy over the 10 year period were calculated.

It was decided not to run the NETPLAN model for each of the 10 years due to the time involved. Further, assumptions would have had to be made concerning the timing of individual plant upgrading and expansion. NETPLAN could have been used to assist in making these timing decisions as described in Chapter 5. However, since the study was concerned with strategic organisational aspects rather than the specific detail of how and when the 1990 production capability was to be achieved, the accuracy obtained from additional runs was considered by the consultants to be inappropriate (BBA, 1981, III).

## 8.7 The NETPLAN Models

Different sets of data were required for the analysis of each of the strategies in the 2 years, although there were a number of common features which characterise the size and complexity of the NETPLAN models used.

The 7065 farm supplies were amalgamated into 238 supply cells. Most of these cells were squares of side length 5 km. These supply cells were also amalgamated into 9 subregions for which supply growth rates were calculated. These growth rates were used to generate the 1990 12 month supply profile for each supply cell, using the SUPGEN program.

Twenty-nine factories, (existing and new) were considered with up to five processes at each factory, and up to four products and by-products being manufactured per process. Altogether 18 different product categories were specified.

For the single company model, 157 inter factory (diversion) distances were measured. A further 657 supply cell to factory distances were calculated using the ETSCALC program (Chapter 3). This involved determining cartesian co-ordinates for all 7065 farms, and measuring 150 bridging distances between bridge points and factories. The resulting distance network thereby permitted maximum flexibility in milk transport for the network formulation. This model had 145 nodes and 1245 arcs. A typical solution run for all 12 monthly periods cost $400 in computer charges.

For the status quo strategy two distance network and supply files were set up: one for NZCDC and the other for the independent companies. No transhipment of milk between companies was permitted. The results of using the model for these two data sets were combined to give a total analysis of the strategy.

For the independants combine model, the input data was similar to the status quo model, except that the distance network was expanded to allow milk movement between the independent companies. A different set of factory data was also required reflecting the alternative investment proposals.

The regional companies model used a distance network file similar to the single company strategy, except that movement of milk between the six areas was not allowed. This met the requirement for six self contained supply and processing areas.

All costs were measured in 1979 terms; no account for inflation was made, and no discounting of future costs was carried out, partly due to the fact that the timing of capital expenditures was not determined.

Another simplification was that a standard set of product yields was used. These ignored differences in milk quality, processing efficiencies, and variations in measurement procedures.

From a production planning viewpoint, this simplifcation could cause sub-optimal allocation of milk to factories and processes. However for the strategic planning application, where differences between alternatives were being considered then all alternatives would be more or less equally sub-optimal. These differences would reasonably reflect true differences in benefits.

In addition this simplification was appropriate since the huge data requirements and the task of standardising the yield data would have drawn resources away from what were regarded as more important aspects of the study.

## 8.8 Model Verification

Verification of the model was carried out by the consultants using the 1980 status quo model. Both the product mixes by factory and cost analysis generated by the model compared very well with actual data. Table 8.2 shows the model costing analysis compared with the Dairy Board "Analysis of Manufacturing and Marketing Accounts" (BBA, 1981, III).

Table 8.2: Cost Analysis Verification

| | Model Results | | Dairy Board Analysis* |
|---|---|---|---|
| | $(m) | | $(m) |
| Milk: variable processing costs | 25.298 | ) | |
| fixed overhead costs | 33.797 | ) | 59.686 |
| Cream: variable processing costs | 9.305 | ) | |
| fixed overhead costs | 7.552 | ) | 16.532 |
| | 75.952 | | 76.218 |
| Transport costs | 14.291 | | 14.154 |
| | $90.243 | | $90.372 |

*Note: excludes BMP and whey processing costs as well as AMF reworking and butter patting costs.

## 8.9 Results

Table 8.3 summarises the results of the economic analysis over the 10 year planning period. The status quo strategy was taken as a control, and the differences in costs between the other strategies and the control are shown.

The principal result is that, as expected, the single company strategy shows the greatest possible cost savings of $96 million when compared with the status quo. However the regional companies strategy was very close, achieving virtually identical transport and processing cost savings.

Table 8.3: Economic Effects over 10 Years ($m savings in costs compared with 'status quo' strategy) (BBA, 1981, III)

| | Independents Combine | Regional Companies | Single Company |
|---|---|---|---|
| Transport savings | - 1.985 | 14.720 | 15.840 |
| Processing savings | 10.255 | 20.450 | 20.240 |
| Administrative savings | 2.000 | 1.850 | 2.300 |
| Sub-total: operating costs | 10.270 | 37.020 | 38.380 |
| Capital savings | 42.200 | 51.660 | 57.650 |
| Total | 52.47 | 88.68 | 96.03 |

Note: Transport costs include inter-factory diversion costs and collection costs. Processing costs include fixed and variable costs.

The reduction in transport costs contributed substantially to the benefits achieved by the regional and single company strategies. Further, the transport saving component increased from $1.304 million in 1980 to $2.467 million in 1990. The proportion of transport cost savings to annual operating cost savings also increased indicating that the advantages of a more rational industry structure would become greater as time passed on. This ratio increased from 38% in 1980 to 56% in 1990.

Upon considering non-quantifiable aspects of the two most economic strategies, the consultants recommended the adoption of the regional strategy by the industry. After discussing the consultant's report (BBA, 1981, III summarised in (NZDE, 1981, III)) the companies could not agree on the recommendations. Since then, however, some progress has been made with regard to independent companies combining, while some farmers have chosen to switch to supplying the NZCDC Ltd. (NZDE, 1982, I, II)

## 8.10 Conclusions

The NETPLAN model was used by a team of consultants to investigate the economic benefits of restructuring the dairy processing industry in the South Auckland and Bay of Plenty regions. Although the model was considerably larger (in terms of data requirements and network formulation) than the earlier NZCDC version, its performance completely satisfied the consultants.

Nevertheless a number of simplifications to the model were employed for reasons of cost, time and effort, and the fact that the model was used to solve a strategic problem, rather than a more specific factory location type of problem.

Cost savings of nearly \$100 million over 10 years were indicated by the model for the most economic strategies. The importance of transport as a component of total cost was re-emphasised, through cost savings amounting to nearly \$2.5 million per year at the end of the planning horizon, which represented 56% of the annual operating cost savings.

Overall, the adaptation of the model proceeded in an orderly manner according to a planned schedule. This indicates first that the design of NETPLAN was sufficiently flexible to meet new planning requirements. Second, that the model was in a user-oriented form capable of being taken over and used by people who had been completely unrelated to the initial model development activity.

# CHAPTER 9

# CONCLUSIONS

## 9.1 Introduction

This chapter summarises the main conclusions and contributions made by the current study. Indications about areas for further research are made.

## 9.2 Summary of results

The principal objective of the current study was to establish a Decision Support System for application to location planning and other long term corporate planning tasks in a dairy products manufacturing company. This objective was met by integrating a set of powerful mathematical modelling techniques with a user-oriented computer system. Implementation of this hardware and software within the company's decision making procedures was achieved through establishing an appreciation of the model's capabilities with the company's decision makers combined with appropriate documentation, training, and validation.

Features contributing to the successful adoption by the company of the DSS were:

(a) The use of a developmental modelling approach. That is, a repeating cycle of problem examination or review, model formulation, validation and implementation. Each cycle incorporated some aspects of the previous model, so that comparative testing could be carried out. This process also facilitated user acceptance since less learning was required to become familiar with the new model.

(b) Use of modelling formulations which were readily explainable to company personnel: network programming; expected travelling salesman distances; discounted cash flow; fixed cost minimization heuristics.

(c) A fast, interactive system which permitted rapid model evaluation and timely application to planning problems.

(d) Minimization of user frustration due to hardware or software failure or other interuption through use of

- microcomputer for off-line data editing and graphing tasks.

- independent programs (NETPLAN, NETAG etc) which communicated with each other via permanent (disk) storage.

(e) Maximization of model understanding through a variety of computer generated graphics and special-purpose reports.

(f) Other programming approaches which had the objective of improving the 'hands on' user's effectiveness:

- model presolution feasibility checking
- speedy command entry checking
- ability to 'freeze' a model's data for use at a later session.

(g) Last, but not least, was the general company interest and support, and the capability and enthusiasm of the company's staff analyst.

Scott-Morton (see Chapter 3) suggested that successful computer-aided planning was associated with the provision of computer support for a small, clearly identified and reasonably well-understood component of the overall planning process and the simplicity of the related computer systems development. He also suggested that success was not related so much to the level of sophistication of the management science models involved. Although the initial intention of this study was to accept these suggestions the results have indicated the converse. Although the computer system which resulted appears to the user as being relatively simple, what lies within the 'black box' certainly is not. The initial location planning task appeared simple, but when the seasonal and annual variations in milk supply, tanker load size, and product prices were considered along with the fact that a 'green field' approach was a completely impractical solution, the planning process becomes rather less clear. Simple models were initially used in order to meet the company's immediate requirements. But the company itself recognised the limitation of the simpler models and thereby supported the development of models that could approach a more ideal or optimal solution.

This supports the recent findings by Hederstierna (1982) who carried out a survey to determine what characteristics of a DSS were rated as important to different personnel in the management hierarchy of a publishing company. He found that whereas the 'hands on' user preferred a fast, simple model, more senior managers preferred that all relevant factors be considered and that an optimal solution was likely to be found.

Resulting from this work, then, have been contributions to the methodology of "enhancing the coupling of human skill and judgement with the ... power of computer systems" (Scott-Morton) with particular reference to corporate-level planning. Some contribution has been made to the field of applied network programming. In particular, a method of coping with a multiple product and by-product demands under varying process yields was described.

The benefits of a well structured network, employing the concept of 'phases' were emphasised. These benefits are: ability to carry out pre-solution feasibility checking and ease of expanding the model to achieve greater realism.

Improvements were made to Sa's heuristic procedure for minimizing fixed costs, with ordinary and overtime variable costs. These improvements resulted from taking advantage of the structure of the problem under consideration, in addition to employing Balinski's relaxation as a starting basis for the 'drop phase' of the heuristic. The benefit achieved was that a good solution to the fixed charge problem could be obtained in a short, reasonably predictable time. Concurrently, an indication as to the maximum degree of suboptimality was provided to the user so that he could choose whether or not to continue the search procedure.

Eilon et al's method of predicting the tour length of a travelling salesman was found useful in predicting the road distance travelled by a milk tanker. Extensions were made in three aspects of their method:

(a) coping with the monthly variation in milk supplied per farm (that is, a seasonally varying number of customers were visited per trip).

(b) coping with the non-ideal transport network through the introduction of measured 'bridging distances' between a factory and group of farms.

(c) integrating the resulting hybrid expected travelling salesman distances model with a network flow model.

In conclusion, the DSS that was developed had a high degree of realism, yet was flexible and fast enough in operation to allow its use in a wide range of corporate planning activities. These activities included location and timing of factory capacity investments; takeover, merger and industry rationalization studies; and an insurance problem.

## 9.3 Further research

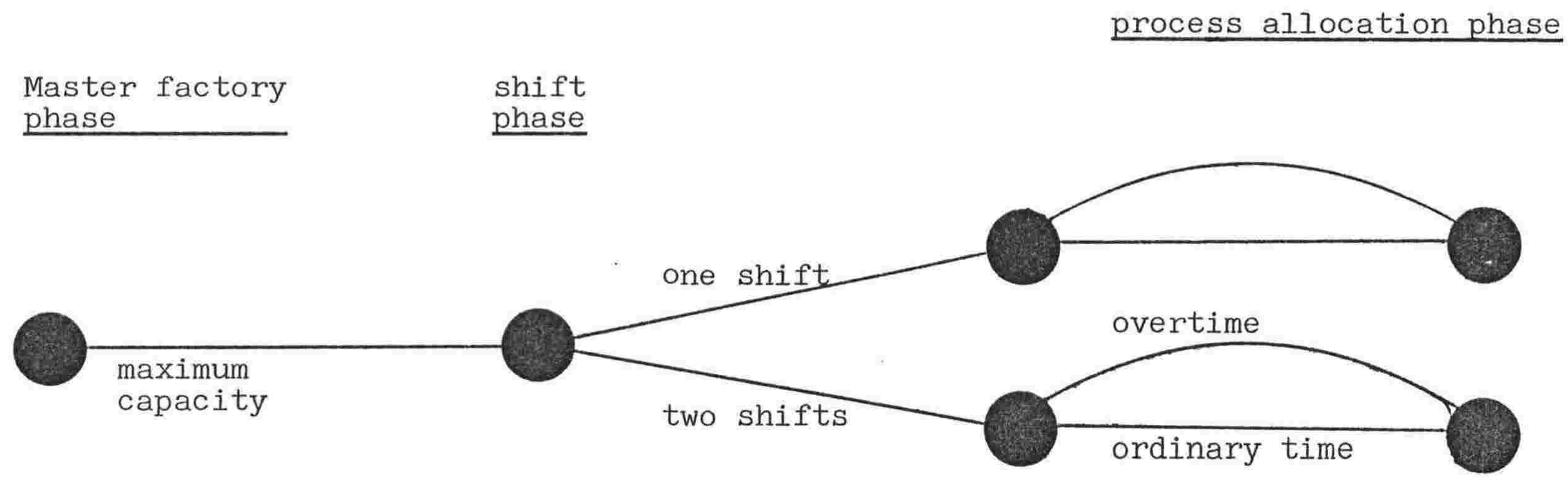
The model and data as currently established form a base upon which more comprehensive or more detailed models could be developed. The model can be used to identify to some extent what the company could gain from, for example, a model which carries out a multi-period optimization including fixed daily and annual costs. (Section 5.4).

This could be approached using the network formulation used by Klingman et al (1976) in their cotton ginning problem, although their model did not handle more than one product type.

The DSS could be reoriented in order to deal with both long term and short term (production) planning requirements. For example, the model solution output indicating which farm groups supply which factories could be integrated with a tanker scheduling procedure such as that of Roper (1981). The optimal mix of overtime and shifts worked at a given factory on a given day can be incorporated into the current formulation by replacing the factory input and process allocation phases (phases IV and V, Chapter 4) with three new phases. These are a master factory phase, a shift phase and an allocation phase (Figure 9.1). The master factory phase simply specifies the maximum quantity of milk that can be processed by a factory operating continuously (3-shifts). Next, the milk is allocated into one of a number of arcs representing a one shift, two shift or three shift factory. The capacity of these arcs represents the maximum possible for the particular shift (ordinary time plus overtime) as in Section 5.2. A fixed cost for the number of shifts is associated with each arc. Finally, in the process allocation phase, an ordinary time and overtime net variable revenue and process capacity are specified, as in Section 5.2

In solving this problem, the master factory phase would only be active in the Balinski relaxation and the subsequent Balinski drop phase (Appendix 2). It would ensure that milk was not allocated

FIGURE 9.1 INCLUSION OF SHIFT COSTS




NOTE: only two shifts configurations shown for clarity.

simultaneously to all three factory configurations. It is still possible that the network program could allocate milk to the one shift and two shift operations rather than to the three shift operation. With actual data this is unlikely to occur since the fixed costs of operating a factory for three shifts would generally be less than the sum of fixed costs for a one shift and two shift operation. The Balinski relaxed cost would therefore be lowest for the three shift operation.

In the add phase and swap phase of the heuristic developed in Chapter 5, an additional presolution feasibility test would ensure that no subproblem is solved which has more than one arc open per factory in the shift phase of the network.

This formulation was inappropriate for the current study because the emphasis was with longer term rather than tactical planning. However, the current model can be used to test the benefits of such an improved model through ad hoc changes in factory costs and capacities.

As the company continues to diversify its product range and seeks to increase the value obtained from its byproducts, the pure network programming approach will begin to prove inadequate if a global optimization is to be achieved. Whether the generalized network programming codes currently under development (McBride, 1982) will be adequate for this task remains to be seen. The alternative, a specialized solution procedure for the dairy company situation might prove better in the short run. The experience in this study, however, is that the flexibility of design and development afforded by a widely-applicable technique such as network programming pays great dividends in terms of the modelling effort needed to adapt to new requirements.

Another general observation is that limitations to the mathematical formulation (e.g. in terms of optimality) can be overcome by the design of the overall DSS within which the model is embedded. For example with graphics display of the model's output, the user can very much more rapidly understand the solution and subsequently tune the model in the light of any special constraints which must be imposed.

Fast program turnaround and simple command entry features also support this tuning process. For a more complex model, with more data or more structures (e.g. phases in this model, section 4.3) research into more effective methods of model manipulation and solution presentation would be rewarding. For example, adaptation of much of the technology used in Computer Aided Design (CAD), such as dynamic colour graphics, light-pen command and data entry, and multi-dimensionally oriented software.

Much of what has been said so far has been concerned with 'deepening' the DSS. That is, improving its ability to help solve the <u>same</u> questions. Effort should also be concentrated on identifying just what <u>kinds</u> of decisions will need to be made in the future. What is required here is an integration of such techniques as strategic analysis (Philips, 1981) and decision analysis (JORS, 1982) with the flexibility and power of the more traditional mathematical modelling approach and the rapidly developing variety of computer systems hardware and software.

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# APPENDIX 1

# CALCULATION OF TANKER DISTANCES

## A1.1 Introduction

This appendix describes the development of a hybrid model for distance prediction for the travelling salesman problem, and validates the model by comparison with actual distances travelled by tankers at the NZCDC. The method is also compared with the centre of gravity method, which is shown to severely misrepresent and underestimate the distances travelled.

## A1.2 Expected Travelling Salesman Method

The formula as proposed by Eilon et al (1971) for predicting the total distance travelled by a travelling salesman visiting a number of customers on one round trip is given in Equation A1.1.

This equation assumes:

(a) Customers distributed over a square area according to a random uniform distribution.

(b) The trips made are all optimal "travelling salesman" routes.

(c) All customer demands are equal.

(d) The depot is not located in the centre of the square (slightly different coefficients are required otherwise).

(e) The salesman can travel in a straight line from one customer to another.

Equation A1.1 = <u>Eilon's expected distance for a travelling salesman</u>

$$d = \frac{1.7Z}{\varepsilon} + 1.035Z^{\frac{1}{2}} \; p^{\frac{1}{4}}$$

<u>where</u>

$d$ = total distance travelled to visit all customers (farms)

$Z$ = sum of Euclidean distance from all customers to the depot (factory)

$\varepsilon$ = mean number of customers visited per trip

$p$ = area over which the customers are scattered

These assumptions did not hold for milk collection and so studies were carried out to compare the model with actual collection distances.

Because of the tortuous nature of some of the roads in the collection area, it was found desirable to measure the actual road distance from the factory to a point near the cell. This point is termed a 'bridging point' and the distance is the 'bridging distance' b. See Figure A1.1. Typically, the bridging point and distance could be used in the calculations for a number of other supply cells close by so that not too many measurements need to be made. The total tanker distance travelled can now be seen to be made up of two components:

(a) Travelling salesman distance within the cell.

(b) Bridging distance trips.

The number of trips that the tanker must travel along the bridging distance is given by Equation A1.2. Thus the total distance to be travelled to visit all the customers is as shown in Equation A1.3.

The model in Equation A1.3 was tested by comparison with a number of actual individual tanker trips made by the company. Figure A1.2 shows a plot of the 'actual' versus 'predicted' distances. The correlation ($r^2$ = 96.0%) was sufficiently high to accept the model. A further validation of the whole distance network was later carried out : this is described in Section A1.4.

Because only the value of E varies from period to period, Equation A1.3 can be rewritten as Equation A1.4, where the concept of

Fig. A1.1 The Travelling Salesman Trip

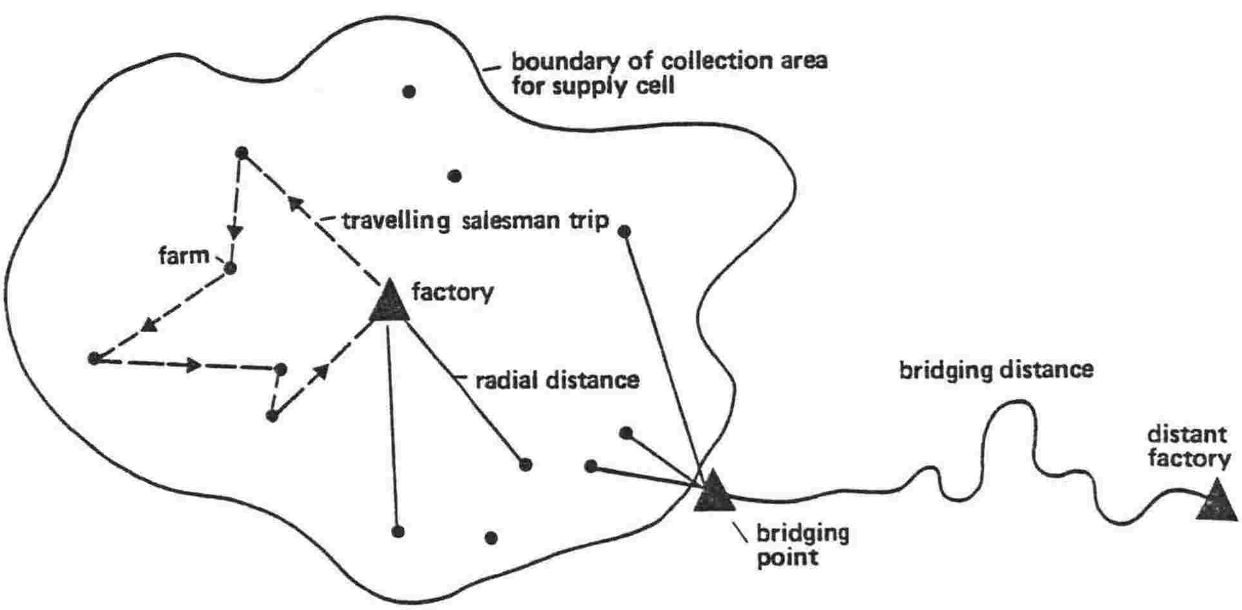
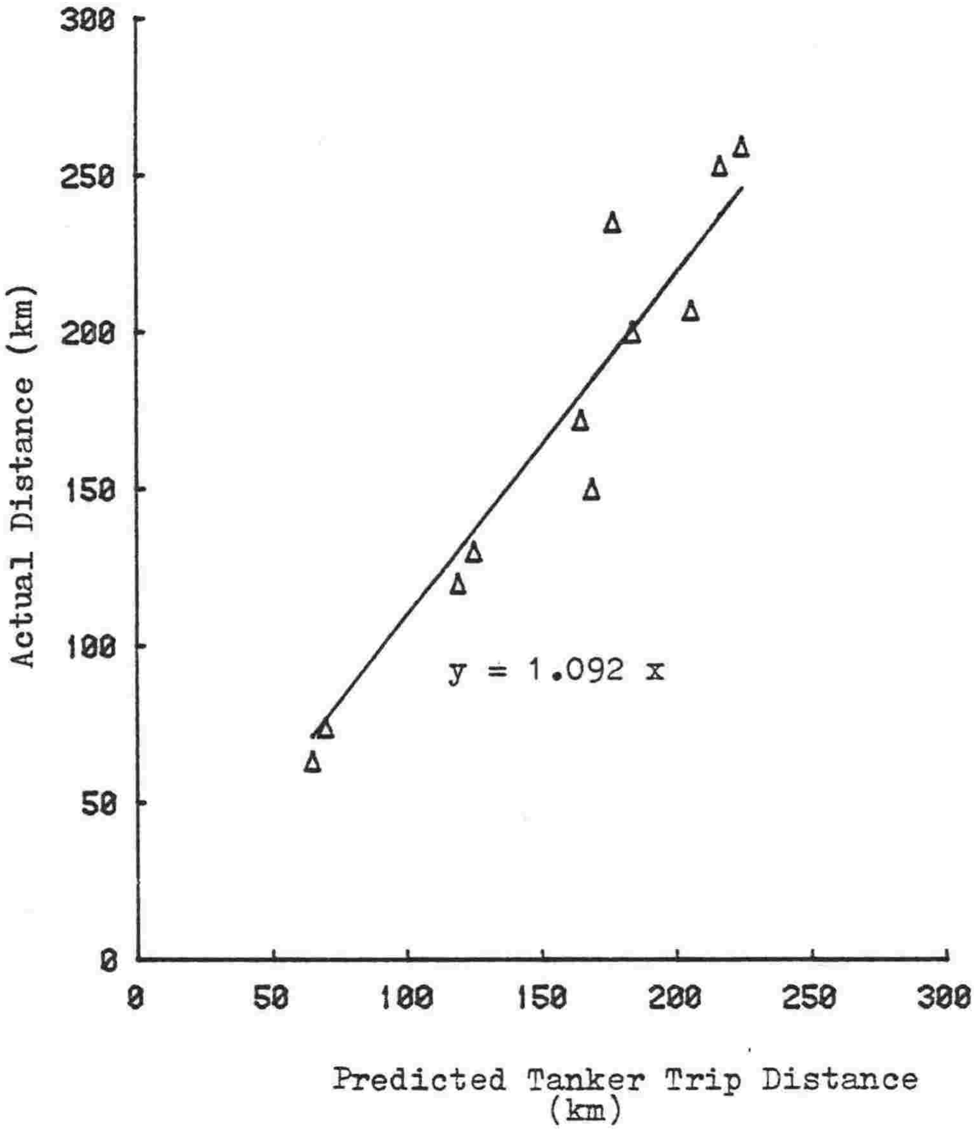


Fig. A1.2

Actual & Theoretical distances for tanker trips



Equation Al.2: Bridging trips

$$t = \frac{2n}{\varepsilon}$$

where

t = number of trips

n = number of farms in supply cell

Equation Al.3: Hybrid distance

$$d = \frac{2nb}{\varepsilon'} + \frac{1.7Z}{\varepsilon'} + 1.035Z^{\frac{1}{2}} p^{\frac{1}{4}}$$

where

b = one-way bridging distance from cell bridging point to factory

Equation A1.4: <u>Distance Seeds</u>

$$d = \frac{L}{\varepsilon} + B$$

$$L = 2nb + 1.7Z$$

$$B = 1.035\ Z^{\frac{1}{2}}\ p^{\frac{1}{4}}$$

where L,B = distance seeds, which are independent of load, $\varepsilon$

'distance seeds' is introduced. This equation allows the calculation of the distance seeds to be made in a computer program, ETSCALC, which is independant of the NETPLAN model program. (Refer to Figure 4.1). This improves the speed of use of NETPLAN, simplifies its use for the user and reduces the amount of data storage required whilst running the model since the distance seeds are fewer in number than the farm, bridge point and factory co-ordinates (896 compared with 4500). The need to use distance seeds in NETPLAN, rather than a calculated distance is because the load factor varies considerably from month to month, as shown in Chapter 4, Table 4.6.

## A1.3 Calculation of the Area of Travel

Eilon's formula, Equation A1.1 assumed a square area over which the customers are scattered. This is generally untrue, and it was found that a more realistic estimate of the travelling area was required. The approach adopted was:

(a) Calculate the area of the minimum sized rectangle which just bounded all the farms in the cell.

(b) Graphically display the farm locations to the user.

(c) Obtain from the user his estimate of the percentage of the rectangle over which he would expect the tanker to travel.

(d) Calculate the result of multiplying the rectangular area by the percentage cover.

Because the area is taken to the power of 0.25, any human errors of estimation are reduced. For example, assuming a rectangular area of 100 units with an estimation error of +/-5 units, the error in $p^{0.25}$ is +/- 4% when the percentage cover is estimated at 30%. For a percentage cover of 80% the error is +/- 1.5%.

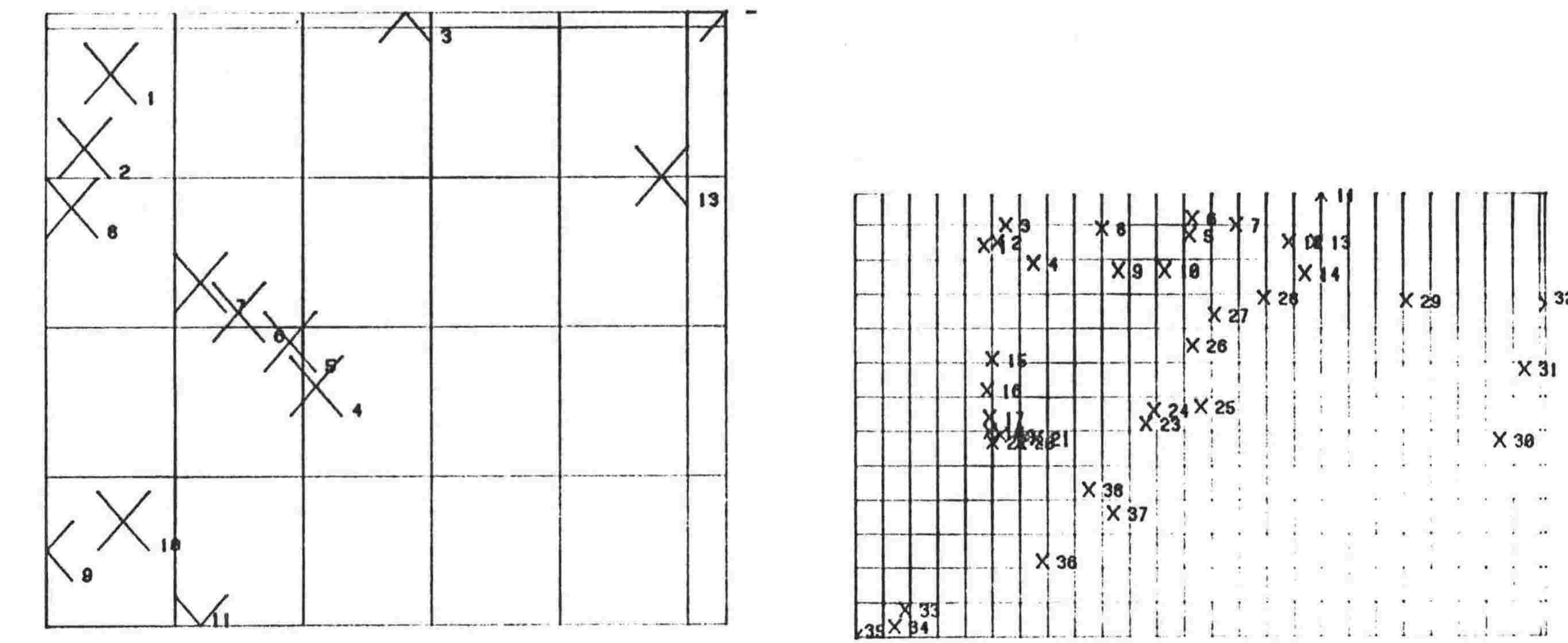
Figure A1.3 shows two typical NETPLAN model cells and their farms as displayed to the user. The first cell has a rectangular area of 18 $km^2$ and percentage cover of 75% giving a tanker coverage area of 13.5 $km^2$. The second cell has a rectangular area of 272 $km^2$, percentage cover of 60% giving a coverage area of 163.2 $km^2$.

## A1.4 Validation of the transport network model

Once the distance seeds data had been generated, the NETPLAN model was run in order to compare the distances predicted with actual distances travelled by the company's tankers. A 'distance minimization' was carried out subject to the factories being constrained to process the actual amount of milk handled in the 1979-80 season. There were some data incompatibilities:

(a) The cell supply data was for 1980-81. It was assumed that the overall monthly pattern of supply would be unchanged from 1979-80, so the supply data was scaled to match that for 1979-80.

(b) The distance network data was for 1980-81. Three factories in 1979-80 had been closed down and had not been incorporated into the network. The 1979-80 milk supplies handled by these factories were therefore added to the nearest available factories.



Nforms = 13 Ngridcells = 1
Gridcell area = 25 Rect area = 18 Estimated % cover = 75 %
Xrange = 3115 3168 Yrange = 5543 5584 Coverage area = 13.5

Nforms = 38 Ngridcells = 9
Gridcell area = 225 Rect area = 272 Estimated % cover = 60 %
Xrange = 2313 2565 Yrange = 5316 5445 Coverage area = 163.2

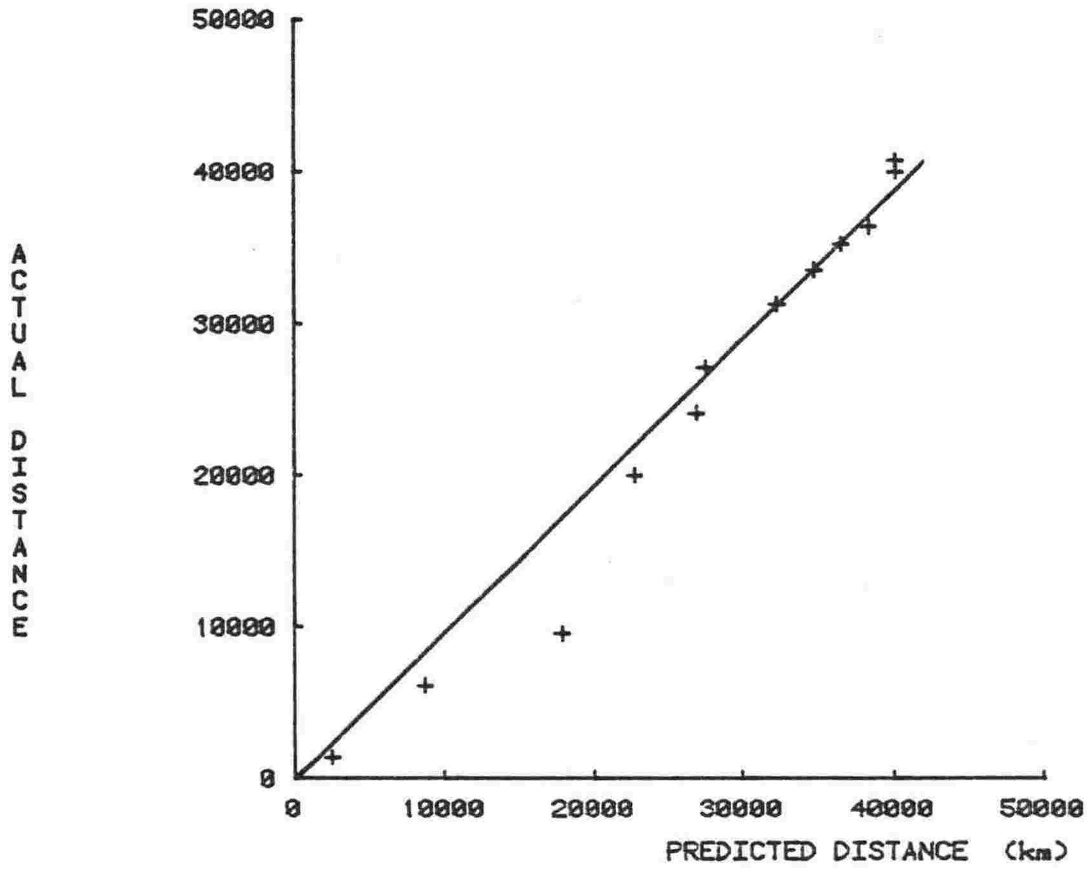
Fig. A1.3 Areas of Two NETPLAN Cells

(c) The actual distances travelled and number of trips made were available for the 15th day of the month, whilst the number of farms visited and factory utilization were available for the 20th day of the month. The volume of milk collected was the average for the month.

Despite these incompatibilities, the results gave a satisfactory correlation ($r^2$ = 98.8%). The data is graphed in Figure A1.4. The model tended to overpredict with respect to actual, and this is partly explained by the shutdown of the three factories requiring extra transport to be carried out. Other reasons for variance are related to the assumptions in the model given in Section A1.2.

A useful refinement found from this experiment was that the value of E in Equation A1.4 had to be determined from the ratio of the total number of farms in the company divided by trips made in the month, as compared with the actual number of farms visited per trip in a month. In most months this distinction had no effect since 'total' and 'actual' were more or less identical. In the low supply months of May, June and July, fewer farms were actually visited (251 for June compared with the total number of 4,485). The distance seeds in Equation A1.4, however, are calculated on the basis that all farms will be visited and so would substantially overpredict distances in these three months. Use of this refined definition of E overcomes the bias.

Fig. A1.4 Actual and Theoretical Distances for the Complete Distance Network



## A1.5 Experimental Comparison of Two Methods of Distance Prediction

An earlier model of the NZCDC milk model employed the centre of gravity method (COG) for estimating cell to factory distances. This section reports on a comparison of the COG method and the hybrid expected travelling salesman method used in the current model.

The COG method used was:

(a) Using all the farm locations in a particular cell, determine the mean x and y location. This is the centre of gravity (COG).

(b) Measure the road distance from the COG to the required factory.

Costs per unit of flow were calculated from Equation A1.5.

It can be seen that this method will give rise to a distorted representation of the transport costs. For example, consider a cell whose COG happens to coincide with the factory's location. In this case ($d = 0$) and no transport cost would be incurred. In reality, the tanker does travel a finite distance around the factory, and this is predicted appropriately when Equation A1.3 is used.

The experiment comparing the ETS and COG methods involved using the NETPLAN models to minimise transport costs subject to all supplies being processed, and using a typical set of factory capacities. No minimum capacities were set. Table A1.1 shows the

Equation A1.5: <u>Centre of Gravity Network Costs</u>

$$c = \frac{2\ d\ t}{k}$$

<u>where</u>

d = distance from cell to factory, km

t = transport cost per km

k = tanker load carried, kl

actual capacities used, and differences for the two methods for October and August. The table shows that some large differences occur. When percentage differences are considered there is a tendency towards greater variation in August. This effect is summarised by calculating the mean of the absolute value of the percentage differences (M.A.P.D.) as shown at the bottom of the table. This greater variation in August arises because none of the milk flows to the factories are limited by the factory capacities in that month. In October four of the ten factories have reached maximum capacity.

Table A1.2 compares the total distance travelled under the two methods. The COG method underestimates the distance travelled when compared with the ETS method, as was expected.

Table A1.1: Comparison of Capacity Utilisation for the ETS and COG Methods

| | October | | | | August | | | |
|---|---|---|---|---|---|---|---|---|
| Maximum Capacity | ETS Utilisation | COG Utilisation | Difference | % Difference | ETS Utilisation | COG Utilisation | Difference | % Difference |
| 72 | 72 | 72 | 0 | 0 | 64 | 64 | 0 | 0 |
| 1000 | 1000 | 927 | 73 | 7.3 | 623 | 567 | 56 | 9.0 |
| 1550 | 1337 | 1396 | -59 | -4.4 | 714 | 753 | - 39 | - 5.5 |
| 1350 | 1350 | 1348 | 2 | 0.1 | 706 | 573 | 133 | 18.8 |
| 750 | 651 | 502 | 149 | 22.9 | 127 | 183 | - 56 | -44.1 |
| 1630 | 1251 | 1380 | -129 | -10.3 | 558 | 730 | -172 | -30.8 |
| 1390 | 917 | 899 | 18 | 2.0 | 407 | 343 | 64 | 15.7 |
| 1590 | 1590 | 1590 | 0 | 0 | 862 | 874 | - 12 | - 1.4 |
| 1000 | 856 | 714 | 142 | 16.6 | 99 | 84 | 15 | 15.2 |
| 1300 | 1051 | 1242 | -191 | -18.2 | 469 | 455 | 14 | 3.0 |
| Mean absolute percent difference | | | | 8.2 | M.A.P.D. | | | 14.3 |

Table A1.2: Total Collection Distances for the ETS and COG Methods

| | October | | August | |
|---|---|---|---|---|
| | ETS | COG | ETS | COG |
| Distance, km | 41,071 | 25,425 | 25,815 | 22,300 |

# APPENDIX 2

## THE ITERATION PROCEDURE FOR GLOBAL PRODUCT CONSTRAINTS

The yield of product per unit of milk varies from factory to factory (see section 4.3). However the constraints on the global demand arc must be expressed in units of milk rather than in product units. Using the mean product yield would not generally give correct results so an iteration procedure is required which varies the demand and constraints until certain conditions are met.

The iteration procedure operates as follows:

1. Calculate a mean yield $y$ for the product for the company as a whole, by dividing maximum possible company production of the product by the milk flow required to achieve this level of production.

2. Use $y$ to calculate minimum and maximum capacities ($l$ and $u$) on the global product demand arc, in terms of the milk input.

   $$l = q/y$$
   $$u = r/y$$

   where $q$ and $r$ are the lower and upper product requirements.

3. Solve the network, using the previous optimal basis if one exists.

4. Calculate the total amount of product made $h$ using process flows and individual process yields from the network solution.

5. Calculate the flow $f$ required to produce $h$.

6. Calculate $y_r$ the resulting mean company yield of product per unit of milk flow along the global product demand arc.

$$y_r = h/f$$

7. Terminate the iteration procedure only if the total amount of product made falls within the product minimum and maximum production required.

$$(q - y) <= h <= (r + y)$$

where y is used as a tolerance because the network flows are allocated in integral multiples of kilolitres of milk.

A second termination condition requires that the value of y used to set the minimum and maximum arc constraints is reasonably close to the resulting average unit yield (otherwise the arc constraints would be incorrectly specified).

$$(y - e) <= y_r <= (y + e)$$

$e$ = a tolerance factor

8. If the termination conditions are not met, then re-estimate y using $y_r$ and the previous value of y then go to step 2

$$y' = m\,y + (1 - m)\,y_r$$

where m = a weighting factor between 0 and 1.

y' = re-estimate of y.

The smoothing function is required because the marginal value of y may not be equal to the mean value of y.

Values of e and m found to be most effective were 0.005 and 0.2 respectively. The iteration procedure usually terminates within five iterations.

Although Figure 4.5 and the above procedure describe just one global product demand arc, the NETPLAN model may have more than one demand arc. In this case the termination conditions in Step 7 must be satisfied simultaneously by all the different products.

# APPENDIX 3

## THE MODIFIED FIXED CHARGE HEURISTIC PROCEDURE

This appendix outlines the modified heuristic procedure for solving the fixed charge problem described in Chapter 5. In addition to the variables described in that chapter the following are employed:

status = array of length equal to the number of fixed charge arcs.
The values of status for a given arc (a) are on, relaxed or off. Depending on the arc's status, either the true variable cost, relaxed cost (Equation 5.1) or Big M cost are included in the network being solved.

incumbent = array like status which holds the arc status for all arcs in the current best found solution.

found = boolean flag indicating whether a new incumbent has been found.

marked = array used to keep track of whether an arc has been dropped or added. If marked (a) = true then the arc will not be selected again.

$a_k$ = the last arc to be dropped or Balinski - dropped.

$a_1$ = arc to be added.

$a_o$ = arc to be dropped.

X = solution flow vector from the Out-of-Kilter algorithm.

$X_{inc}$ = best found solution flow vector.

P = shadow price vector.

$P_{inc}$ = best found shadow price vector.

The criteria for arc selection were given in Chapter 5. The 'solve' process includes pre-feasibility tests and calculation of true (unrelaxed) costs, T. For solution by the Out-of-Kilter algorithm, the incumbent flow and shadow price vectors are used as a starting basis. This gives a small improvement (7%) in solution time compared with when the previous flow solution is used as a starting basis.

The 'update incumbency' process involves:

$T_{inc}$ = T

$X_{inc}$ = X

$P_{inc}$ = P

incumbent = status

STEP 1. <u>Solve variable cost network</u>

$X_{inc}$ = 0

$P_{inc}$ = 0

status = on

solve NP

$T_{min}$ = T

if $T_{min}$ = 00 then terminate

STEP 2. Solve Balinski relaxation

status = relaxed

solve NP

$T_{Bal}$ = T

$t_{rlx}$ = t

Update incumbency

STEP 3. Balinski Drop Phase

B : Repeat until all arcs

have status <> relaxed.

Select arc to be dropped, a

status (a) = off

solve NP

if T < = $T_{inc}$

then $a_k$ = a

Update incumbency

else status (a) = on

incumbent (a) = on

End B :

Solve NP

if T < = $T_{inc}$

then Update incumbency

STEP 4.

<u>Add Phase</u>

```
found  =  false

marked =  false

marked (a_k) = true

A : Repeat until either new incumbent
      found, (found = true)
      or until no more arcs are to be added

      Select unmarked arc to add, a
      marked (a)  =  true
      status (a)  =  on
      solve NP
      if T < = T_inc
      then update incumbency
        found  =  true
        marked (j) = false for all j
           with status (j) = off
      else status (a)  =  on

End A :
```

STEP 5.

```
If found = true
then go to step 9
```

STEP 6. <u>Swap Phase</u>

found = false

marked = false

generate swap table

S : repeat until either

found = true, or

swap table is emptied.

Select arc to be dropped, $a_o$ and arc to be added, $a_1$

status ($a_o$) = off

status ($a_1$) = on

solve NP

If $T < T_{inc}$

then update incumbency

found = true

else status ($a_o$) = on

status ($a_1$) = off

End S :

STEP 7. If found = true

then go to step 9

STEP 8. <u>Termination</u>

status = incumbent

solve NP

suboptimality = $T_{inc} - t_{rlx}$

Stop

STEP 9. Drop Phase

```
D : Repeat until no more arcs are
    to be dropped
    Select unmarked arc to drop, a
    marked (a) = true
    status (a) = off
    solve NP
    if T < T_inc
    then  update incumbency
          a_k = a

    else status (a) = on

End D :
```

Go to step 4.