COMPUTER SIMULATION OF ORE TRANSPORT AND HANDLING OPERATIONS

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ABSTRACT *The Mt Newman Mining Company Pty Ltd (MNM) operates one of the world's largest iron ore mining, railing and shipping projects. Average annual tonnages are approximately 30-35 Mt and plans have been prepared to increase this tonnage through the development of other ore bodies.*

The paper describes the application of computer simulation modelling techniques to assist decision makers in choosing alternatives that avoid unnecessary capital expenditure by identifying production bottlenecks and quantifying the effects of proposed changes. A brief overview of the different models and their application is presented along with a discussion of the simulation language used. The potential use of animated simulations in presenting results to operating personnel and management is also discussed.

INTRODUCTION

Computer simulation of complex systems has been used for a number of years in many environments to assess operating constraints and capacity expansion proposals. The most significant advantage of simulation as a planning tool is the ability to answer complicated "what if?" type questions, in particular, highlighting effects in other parts of the system under study, that may not be apparent in a simple analysis. The increasing power of today's micro-computers effectively puts into the hands of the analyst or investigator, computing power available on mainframe machines only 5-10 years ago. In addition, today's simulation software provides facilities that enable graphic displays of systems to be presented in ways that operating and management personnel can understand and relate to, overcoming one of the simulation analyst's greatest problems - clearly conveying the results of a modelling study.

This paper presents some general findings of a series of simulation studies carried out by the Mt. Newman Mining Company, discusses the structure of the models constructed and the languages used in simulating and investigating the operations of a large iron ore railing, processing and shipping project.

The Pilbara Region

The Pilbara region of Western Australia supplies iron ore to steelmakers in Australia, Asia and Europe and supports four private mining operations, each operating their own mines, railways and shipping facilities as outlined below.

TABLE 1. PILBARA IRON ORE PRODUCERS

Company	Mining	Rail[1]	Shipping	Throughput[2]
Mt. Newman Mining	Newman	420km	Port Hedland	35-40mtpy
Hamersley Iron	Tom Price Paraburdoo	389km	Dampier	40-45mtpy
Robe River Iron Assoc.	Pannawonica	185km	Cape Lambert	15-20mtpy
Goldsworthy Mining	Shay Gap	179km	Port Hedland	5-10mtpy

Australian iron ore exports for CY1987 totalled 83.5 million tonnes, generating export revenue of A$ 1.7 billion (WAIOICC, p2).

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[1] Source: Railways of Australia, 1988 Yearbook and Personnel Directory

[2] Estimated from data in WAIOICC, Information Paper No. 13.

The operations of all four producers are basically similar, differing only in minor ways depending on the location and type of ore deposit and degree of processing carried out at the railhead. This apparent duplication of infrastructure is the result of several factors, not the least of which is isolation. The nearest Australian capital city is Perth, some 1300km by air and 1800km by road from Port Hedland. Each mine and port site requires accommodation for the workforce and their families as well as support services in the form of retail facilities and public utilities. Government policy during the development phase of the industry favoured decentralisation and the prime customers, the Japanese steel producers, encouraged the separate developments on the basis of reduced likelihood of interruptions to supply from such events as cyclones affecting all producers simultaneously.

The highly competitive nature of the international iron ore trade has sharply focussed the attention of the Pilbara producers on maximising the utilisation of the existing railway and shipping infrastructure. Recent agreements between China and Eastern European customers point to an emerging trend in new project development. A World Bank study (Franz et al, 1986) concluded that, based on the demand forecasts assumed at the time, there were about twenty potential new projects, with a total capacity of over 200 million tonnes, available for a base case requirement of only 15 million tonnes additional capacity and that only one or possibly two of these projects were likely to be implemented. The study suggested that these additional projects were likely to be expansions or additions to existing mines due to the significantly lower capital costs.

The Mt. Newman Mining Company

The Mt. Newman Mining Company Pty. Ltd. (MNM) is a wholly owned subsidiary of the Broken Hill Proprietary Company (BHP) and operates the Mt. Newman Joint Venture on behalf of the owners (BHP - 85%, Mitsui - C. Itoh 15%).

Mining is concentrated at the Mt. Whaleback mine site, however smaller deposits have been opened nearby as additional ore sources. The company operates a 420 kilometre long private railway between the mine at Newman and the ore dumping, processing and shipping facilities at Port Hedland on the coast. Traffic on the railway mainline is controlled from a Centralised Traffic Control at Port Hedland and consists of up to six 240 car Locotrol[3] trains daily, hauled by four GE Dash 7 or five ALCO M636 diesel electric locomotives. The gross trailing load of a Locotrol train can be in excess of 32,000 tonnes making them the longest, heaviest trains in operation in Australia. Scheduled round trip time for a train from the Port to Mine and return is approximately 20 hours.

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[3] Locotrol is a system whereby unmanned slave locomotives, usually located half to two-thirds down the train are controlled by radio from the lead locomotive. Trains are manned by a two-man crew.

The Port operations department is responsible for train unloading or dumping, crushing, screening and stacking of the two main products (lumps and fines) and the loading of ships. The record MNM cargo, loaded into a single vessel, was 234,544 tonnes in May, 1988. As well as the scale problems associated with such a project, there is also a quality consideration. The railed product is blended with material already in the stockyard to form stockpiles of shippable ore conforming to specified grade characteristics. In addition to the iron grade (62-65% Fe), impurities such as phosphorous, silica and alumina have to be kept within fine tolerances to avoid disrupting the steel making operation at the customers' works.

Figure 1 opposite presents a simplified diagram of the ore flow through the Port from the car dumper to the shiploader.

The current stockyard configuration allows for a working capacity of approximately 5 million tonnes of ore to be held, however during the industry downturn in 1983-84, total stocks exceeded 7 million tonnes. The problem being addressed is the management of the differences between railing and shipping tonnages while maintaining the product quality and grade. The simulation models role is to quantify the effects of alternative management strategies.

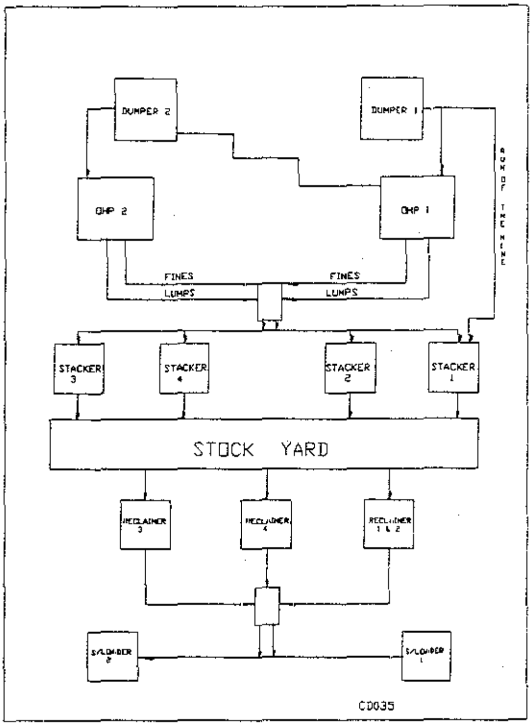

FIG 1: PORT HEDLAND ORE FLOW

SIMULATION LANGUAGE

Development of Simulation Languages

Simulation of manufacturing and continuous processes has been practised over the last two decades for predicting bottle-necks, production rates and resource utilisation. Early models were written in general purpose languages such as FORTRAN, ALGOL and COBOL, however these models tended to be bulky, hard to amend and generally not portable between machines (unless identical). Specific simulation languages such as GPSS, SIMSCRIPT and SIMULA were developed in the 1960's and overcame many of these difficulties.

As the microcomputer has become more powerful and capable of accessing more memory, new simulation languages have evolved, often derived from main-frame based languages. GASP, SLAM, SIMAN and SEE-WHY run on microcomputers and provide the researcher with a relatively cheap, flexible, portable environment for developing simulation models (see Arthur et al, 1986).

The development of high resolution graphics for microcomputers has added another dimension to simulation modelling. One of the shortcomings of the simulation approach has been that outputs have typically taken the form of summary statistics or simple graphs. Although these statistics are necessary to draw conclusions, they provide little or no insight into the dynamic interactions within a model. Animation of a simulation model using high resolution graphics solves this problem. It enables the analyst to more easily verify the model (the analyst can literally "see" where it goes wrong and fix the suspect program code or data accordingly) and it helps "sell the solution". The client can satisfy himself that the model does in fact represent the system under study without having to wade through mountains of printout.

The Siman Simulation Language

The SIMAN (SIMulation ANalysis) language was chosen by MNM as a microcomputer based simulation language because of its recent development, its ability to run on an IBM PC and the support and expertise available in Australia. A model developed in SIMAN could be animated using the CINEMA animation package at a future date if the need arose. SIMAN is a powerful general-purpose process orientated simulation language with full capability for modelling combined discrete and continuous systems. It is designed around a logical modelling framework in which a simulation problem is decomposed into a 'model' component and an 'experiment' component. The model describes the elements of the system such as machines , storage points , work units etc. and their inter-relationships - it contains all the detailed logic of the system. The experiment component specifies the experimental conditions for a run of the model such as machine capabilities and the statistics to be recorded for the run. The experimental conditions are external to the model logic and may be easily changed without affecting the basic model definition. The capability also exists for the user to write and access custom FORTRAN subroutines to augment the SIMAN routines. For a detailed explanation of the workings of the language, see Pegden (1986).

Appendix 1 below indicates how the model and experiment are processed individually and combined to be executed by SIMAN. As the simulation is executed SIMAN automatically saves the responses of any variables specified in the experiment. The SIMAN output processor can then be used to analyse the results to produce plots, tables, barcharts, histograms or correlograms of the saved responses. Examples are given in the detailed discussion of the models below. A review of SIMAN applied to mining systems is given in Mutmansky and Mwasinga (1988).

HISTORY OF SIMULATION AT MNM

Computer simulation has been used on a number of occasions to assess alternative capacity expansion proposals. Purdon and Elbrond (1978) describe a comparison between a GPSS simulation model of the Railroad operation and a queueinq theory approach. The model was used to assess the likely impact of increased numbers of trains and track maintenance requirements as well as the benefits to train running of a track realignment and regrade over the section of ruling grade. This model was later amended and updated to evaluate a variety of proposals regarding train operations (Brown, 1982). Originally run on an IBM mainframe, the Railroad model has been rewritten in SIMAN as two separate models (Mainline and Hedland Marshalling Yard) and currently run on an IBM PC AT.

Concern over possible harbour constraints during the 1970's led to the development of the harbour simulation model. Originally written by members of the Operations Research group at BHP's Newcastle steelworks, the model has been upgraded a number of times. The model was recalibrated in 1986 to take account of the altered shipping rules resulting from the harbour dredging project.

In addition to the prototypes of the models described below, other models have been developed for the Railroad's wagon (ore car) repair shop and certain aspects of the mining operation.

SIMULATION ELSEWHERE

The use of specialised simulation languages for problem solving in Australian transport enterprises would appear to be rare, although there are signs that as a technique it is gaining an increased following. There are perhaps two reasons for the lack of published material on simulation modelling in Australia; the first is that it is likely that not much work is being carried out (or at least by relatively few practicioners) and the second is that the results of such work is usually commercially sensitive, certainly for private companies.

In a review of transportation software, Wadwha (1987) refers to a number of specific in-house simulation programs in use in Australia but notes that most of them are application specific and unfortunately does not report the language the programs are written in.

Englund (1984) discusses different types of simulation and points out the difference between simulation and optimisation techniques such as linear programming. In discussing transport applications (particularly harbours), The point is made that one of the main problems in applying simulation techniques is the communication between the transport manager and the simulation analyst regarding:

(a) misinterpretation of objectives and scope of study
(b) understanding of the system and inter-relationships
(c) difference between the real system and how it is simulated
(d) interpretation of the results and application of subjective judgement

Ellson and Englund (1987) describe the application of simulation techniques to the evaluation and planning of productivity improvements on the Robe River Iron Associates railway in the Pilbara. As noted above, the RRIA operation is similar in many ways to those described here, with a similar concern for determining fleet requirements and throughput for given scenarios. The RRIA model was written in GPSS and run on an IBM mainframe and the authors note the problem associated with the type of output produced by GPSS, in particular communicating the results of the model run to the client.

Welch and Gussow (1986) investigated the relative effects of a number of alternative main line capacity improvements on Canadian National Railway using a SIMSCRIPT model. The study showed that sufficient capacity could be obtained through shortening track sections by adding intermediate signals rather than extensive double tracking. The interaction between traffic and track maintenance was particularly important because of the long lengths of single track on the network. The work resulted in CN being able to defer over C$350 million of capital expenditure. The CN models appear to be similar in many respects to those described by Ellson and Englund and the MNM Railroad models described below. Engelberg (1986) outlines the role of simulation in the automation of hump marshalling yards on CN.

Wolf (1987) discusses the application of simulation to rail transport management at Norfolk Southern Railway. Bell (1985) reviews the impact of animation, particularly for interactive models, on simulation and operations research. Sturgul and Harrison (1987) describe the use of GPSS and simulation in the mining industry based on Australian examples.

CURRENT STUDIES

Mt. Newman's suite of simulation models consists of;

(a) Train Performance Calculator to determine run times and fuel usage
(b) Railroad Mainline Model - mainline operations
(c) Hedland Marshalling Yard Model - shunting operations
(d) Port Stockyard Model - dumping, stacking, reclaiming and shipping
(e) Harbour Model - vessel movements including draft restrictions and tug requirements
(f) Interaction Model - train dumping, port maintenance and fleet requirements

All of the models (except the TPC) overlap to some extent in the sense that various aspects of the operation are covered in differing levels of detail, depending on the particular application under study. For example, the Mainline model covers in some detail signal operation, train running and delays but the yard operation and train dumping are handled by a single queue and a pair of dumping distributions. Similarly, the Harbour model assumes ore always to be available for reclaiming and does not consider stockyard operations at all, being principally concerned with shipping movements. The rationale of this approach (and its problems) is discussed further below.

All of the models are being used to assess the effectiveness, or otherwise, of specific capital or operational improvements to ore transport and handling. As part of the planning process, the simulation studies provide a quantitative measure that can be used as input to the financial and economic evaluations during capital budget preparation. In addition to high level strategic studies the models have also been used to evaluate low level operational problems and potential solutions. These are expanded upon below.

Railroad Studies

The current versions of the Railroad simulation models have evolved from the GPSS model referred to above. Initially developed in-house, the model's shortcomings (and those of GPSS) prompted a major rewrite using a different language. Because of increasing concern within MNM over the ability of the marshalling yard to process an all Locotrol train operation, the model was split to cover mainline and yard operations separately. The redevelopment was carried out by BHP Melbourne Research Laboratories. To date these two models have not been extensively used, due to other commitments of the site officers involved. An attempt has been made to animate the marshalling yard model, however this appears to have been unsuccessful partly because of the complexity of the model (it contains details of all track sections and switches in the yard, shunt locomotives and rakes of cars) and partly because of software limitations. Investigations are currently underway to overcome these problems.

Due to the changes in Railroad operations since the GPSS version was first written, the mainline is no longer seen as a significant bottleneck. Originally designed to handle up to 12 trains per day, current forecasts are for only 6-8 Locotrol trains per day thus problems are more likely to be experienced in the terminals. Studies are being carried out to confirm this and quantify the congestion in the terminal under various railing strategies and timetables.

Port-Railroad Interaction

This model was developed to assess proposed alterations to the ore handling plant maintenance shutdown. The current procedure for carrying out preventative maintenance on the two ore handling plants is to shut down both plants, their attendant conveyors and stackers for approximately 12 hours per week. This arrangement is largely dictated by manpower availability and the physical layout of the plants. Even at fairly low railing rates, the effect of this shutdown was clearly evident in the queueing which occurred in front of the dumpers, mainly on the actual shutdown day (Thursday) as the observed data in Figure 2 shows. Using the observed data to generate various input distributions, a simple single dumper model was written to test the effect of the shutdown scenarios. The model logic replicates the steps taken by trains and rakes of cars through the train cycle (Appendix 2), including the fairly elementary decision of cancelling train departures when insufficient rolling stock is available.

By adjusting the input data distributions for dumping times, the effect of physical improvements in the ore handling plant downstream of the car dumper on train operations could be modelled. This preliminary study indicated that apart from eliminating the shutdown entirely (not a viable proposition), changes to the shutdown arrangements had a slight effect - the more significant variable was the dumping or processing rate.

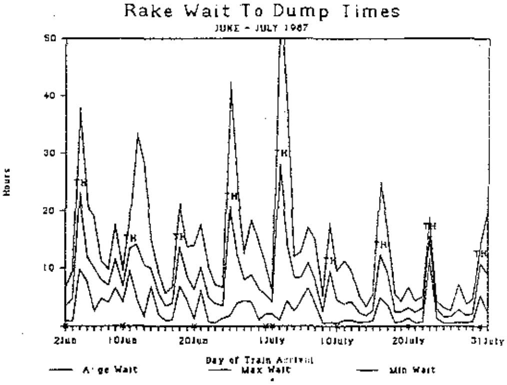

FIG 2. Observed Waiting Time

Figures 3 and 4 below show typical examples of plots obtained from the SIMAN output processor. The particular statistic required (in this case, wait time and rakes waiting to be dumped) can be plotted for any desired portion of the simulation run. Thus problem areas can be identified and examined in considerable detail. Here, the system states are being examined for a period of approximately two weeks, clearly showing the same queueing identified in the real world data.

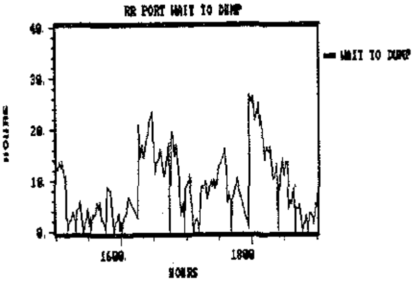

FIG 3. Simulated Waiting Time

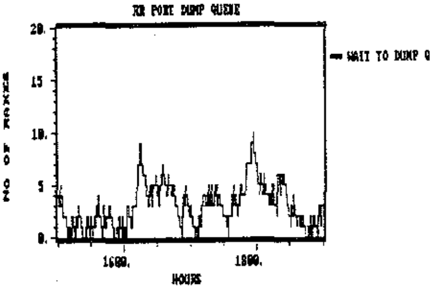

FIG 4. Waiting To Dump Queue

This model has now been enhanced to include the effects of different dumping strategies for different ore types, train dumping using both dumpers simultaneously and specific train departure times for differing train lengths and destinations. A locomotive maintenance module has also been incorporated, however this has not been used extensively pending the availability of locomotive service time data.

With a locomotive fleet of only 53 units, it is highly likely that availability of motive power may become the critical factor in system throughput. The most significant finding that resulted from the use of this relatively simple model was the identification of the high degree of interaction between the Port and Railroad systems and the relative insensitivity of the system to most variables, apart from the processing rate as shown in Figure 5. Previously, this interaction effect had been accounted for in capacity calculations by a simple factor, however the model showed that the effect varies with throughput.

Consideration of a simple queueing system would show this to be an obvious conclusion, however many planning studies are concerned with the performance of particular sub-systems and little consideration given to how all the sub-systems act together. This study showed that the obvious solution of purchasing more rolling stock would yield little additional throughput and that the preferred or more cost effective solution was to increase the ore processing capability through the fixed plant.

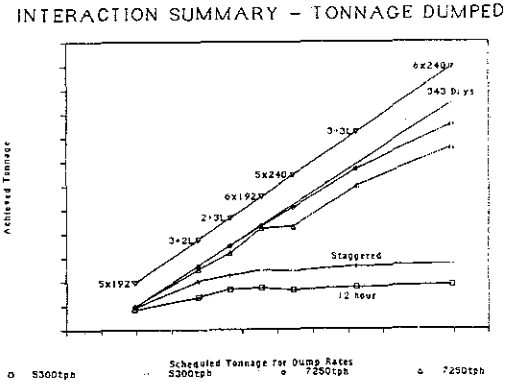

FIG 5. Typical Results

Stockyard Model

With more products being introduced into the MNM operation, it became necessary to investigate the limitations imposed by a fixed stockyard area and ageing equipment. With the complex nature of the yard operations and the fluctuating vessel arrivals, and to a lesser extent the variation between train arrivals, a computer simulation of the yard was seen to be the best method of investigating the yard limitations. Simulation Modelling Services Pty. Ltd. were briefed to develop the model to run on an IBM AT personal computer using the simulation language SIMAN and to be graphically animated using CINEMA.

Stockyard Operations

Trains are generally split into two rakes on arrival at Port Hedland and the rakes are dumped in one of two rotary dumpers that feed the ore processing plants. The ore flow is shown schematically in Figure 1 above. Ore is crushed and screened to produce two products; "lumps" and "fines", which is then fed by conveyor to the stackout system where four rail mounted stackers stack the ore in designated areas. Recent modifications enable limited amounts of special products to bypass the crushing and screening process to be stacked directly in one specific area of the yard.

Four bucket wheel reclaimers are able to reclaim the ore and convey it to two shiploaders at the berthing facilities. Two of the reclaimers are rail mounted on the same rails as two of the stackers and the other two reclaimers are smaller crawler reclaimers that work in unison. This means that one machine may block access of the other on the same track to a particular part of the yard leading to significant delays, particularly during shiploading. This was one of the specific operational problems to be investigated with the model.

Each of the three reclaim systems can feed either of the two shiploaders but only one reclaim system can feed a shiploader at a time. Being mounted on the same tracks enables each loader to service either of the two berths and two loaders can service one vessel if the ore and reclaiming systems are available.

Scope of the Model

The stockyard model does not simulate individual conveyors in the yard but treats each of the main operating areas as separate units with their own rated capacity and availability. The interactions between each of these operating areas is modelled in detail to reproduce the process described above.

The model allows the yard stockpile areas to be defined as required and areas may be dedicated to individual products or may be available for two products. Dead areas of ore that can not be directly reached by the reclaimers can also be included as part of the stockyard layout. The yard layout may be changed to include new stackers and reclaimers with their associated conveyors.

Various railing schedules for different ore types can be set up but the model does not include detailed movements of trains or rakes. The maximum number of ore cars available in the railing system can be specified in the model and a particular railing schedule will only be achieved if all train rakes are processed without an excessive queue of rakes building up outside the dumper. The rate at which ore cars are dumped is determined by the processing and stacking rate downstream of the dumper and allowances are made for equipment breakdowns. Shipping movements are not modelled in detail but the vessel size and arrival pattern can be varied to load up to three different cargoes. The model will use two shiploaders to load a vessel if the necessary equipment and ore is available however the model does not include any quality control aspects and all stockpiles are considered to be "on grade" whether they are completed or are in the process of being built.

Use of The Model

This model is the latest to be developed and is still undergoing final testing, however it reflects the current yard operation and stockpiling strategy. It will be used to investigate the effects of increasing the number of products handled through the yard and the most effective and economical way of increasing throughput capacity of the stockyard. Typical options to be investigated for the effect on capacity include:

- a new reclaiming system
- increasing the number of screens and/or crushers
- increasing conveyor capacities on stackout routes
- introducing a cross yard conveyor system

Figure 6 below shows a typical plot of achievable versus planned tonnages for a particular screening scenario. For example, if more screens were available in the ore processing plants, the ore would be processed faster and fewer trains would be cancelled (for a given fleet size), resulting in a higher yard capacity.

The graph indicates how the divergence between planned and achieved tonnages determines the capacity of the yard. The actual capacity is difficult to ascertain because of the railing and shipping fluctuations that may occur. A constant buffer of stock with regular vessel and train arrivals would be the ideal situation to allow for quality blending of stockpiles and for small fluctuations in arrivals. Yard capacity may also vary with different product mixes.

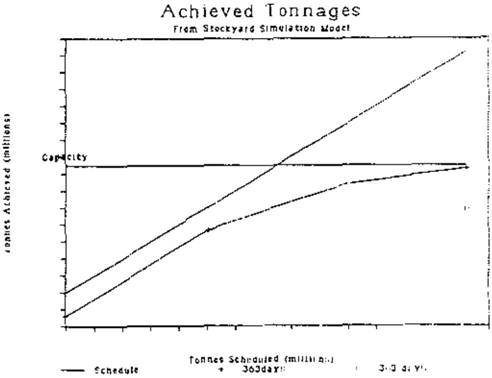

FIG 6. Sample Model Results

Harbour Model

Development Of The Model

A computer simulation of the harbour was originally developed in 1975 in the SIMULA language for use on the BHP Cybernet Network with the aim of analyzing tug and tug manning requirements. The model was modified considerably as more information was required on other areas of the port operations until it became too complex and the results questionable. In 1985 the model was completely re-written with the following objectives:

- to produce a model that reflected the current operating procedures
- to include sufficient detail to ensure that various features of the harbour influenced the harbour capacity correctly
- to provide a flexible planning tool that was easy to use and modify by MNM personnel

The model was developed by the Operations Research Group at BHP Newcastle using SIMULA, the same language in which the original model was written. SIMULA was chosen because of the requirement to run the model on the company IBM mainframe computer and because of the expertise available within BHP.

Scope Of The Model

The harbour model simulates all facets of vessel movement within the harbour and takes into account tidal conditions, underkeel clearances, tug availability, daylight and night time movement restrictions, vessel type and cargo priorities, time between movement restrictions and disruptions due to weather or industrial action. The ship loading at MNM facilities is modelled in detail, with all other users of the port being modelled with statistical distributions of their loading/unloading times.

The availability of the reclaimer/shiploading equipment is not included as this is accounted for in the shiploading rates. These shiploading rates are variable and different statistical distributions can be used for different vessel size classes. The model is capable of evaluating the effects on port capacity of changes in:

- vessel arrival patterns
- vessel sizes
- loading rates
- number of tugs
- level of throughput of other port users
- level of industrial and weather disruptions
- number of berths and berth configurations

The model is usually run for a simulation period of five years to achieve a high level of confidence in the statistical output. This consists of annual averages over the length of the run for;

- tonnes shipped
- number of vessels loaded
- average vessel queue and turnaround time
- loader and berth utilisation

Each scenario being investigated with the model is set up and run for different Mt. Newman tonnage throughputs (assuming other users tonnage is constant) and a plot made of the required statistic (eg. turnaround time, berth occupancy, loader utilisation) against throughput. Thus, the effect of each scenario, or change in parameters, on the harbour capacity can be compared. The Harbour model assumes sufficient ore of the right type and quality is always available.

Use Of The Model

Port, or harbour capacity, is really a subjective topic. In order to maximise the use of the loading facilities at MNM, a constant queue of vessels would be required, however vessel charterers/owners will only use the port if they can be assured of a reasonable vessel turnaround time. Average turnaround times are in fact written into contracts and demurrage fees are payable by MNM when turnaround times fall outside the contracted times. Thus, port capacity may be determined by a maximum acceptable turnaround time that vessel charterers or owners are willing to accept or on the amount the company is willing to pay on demurrage charges.

Figure 7 opposite shows a typical turnaround against throughput plot for two series of runs of the model where different shiploading rates have been used. The figure shows the typical capacity situation in queuing where adding more vessels to the queue will not increase the tonnes throughput once a particular tonnage is reached.

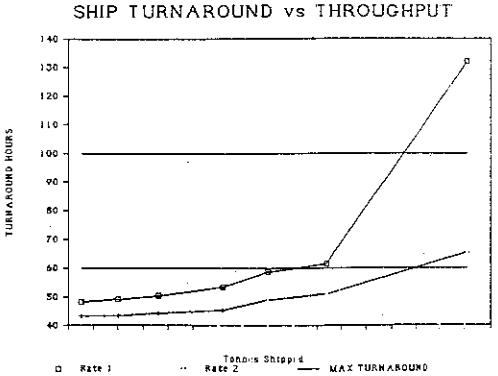

FIG 7. Ship Turnaround Time

This is the real capacity of the harbour, but the capacity as far as MNM is concerned would be set at a maximum turnaround time (say 60 hours as in the figure) which would be acceptable to the vessel charterers and the demurrage acceptable to MNM. Setting acceptable turnaround to another level (say 100 hours) gives a higher throughput, albeit with a higher demurrage cost. Similarly, capacity may be determined by loader/reclaimer equipment utilisation rather than a maximum turnaround time.

Figure 8 opposite shows a typical plot of harbour model results indicating how the loader utilisation increases as tonnage increases. The reclaimer and shiploader equipment may have a maximum availability because of planned maintenance and expected breakdowns so the capacity may be set by this constraint.

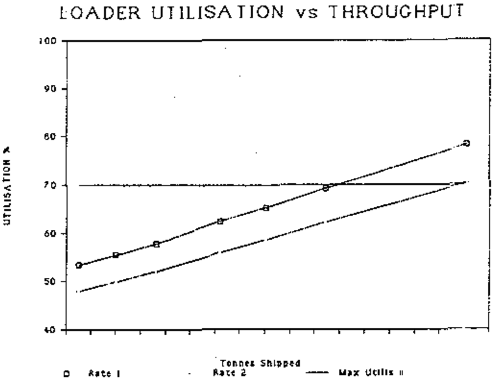

FIG 8. Simulated Shiploader Utilisation

The plot of berth occupancy against tonnage shown in Figure 9 indicates that a maximum berth occupancy of only 85% is achievable because of the restriction of vessel movements to tidal windows and the restriction of specific time intervals between vessel movements. Again, capacity can be inferred from some maximum level of berth utilisation set by external factors.

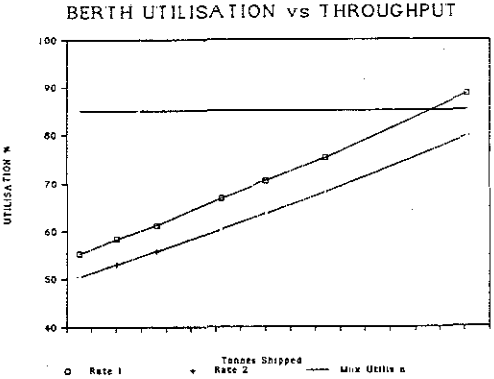

FIG 9. Simulated Berth Utilisation

Additional berths or different berth configurations and capacities can be investigated to help in selecting the most cost effective combination. Because the model uses detailed under keel clearance and tidal movement logic, the effect of different channel depths on the MNM capacity can also be quantified. With larger vessels allowed to berth the capacity would increase for the same berth occupancy and less vessel movements would be required to achieve the same tonnage.

A new reclaiming system to replace an existing one would increase the average shiploading rate which in turn would increase the port capacity. The model was used to investigate the effect of different reclaiming rates on port throughput to identify the most cost effective size of reclaimer.

The harbour model has proved to be an effective planning tool that has assisted MNM in making decisions about large capital outlays. It includes the majority of rules used in the real life operation of the harbour, but as with all models it is a simplification of the real operation and has to be used as such. With the complexities of the inter-related variables within the harbour operations, no other technique, apart from simulation, could provide the necessary quantitative analysis to aid in the justification of capital expenditure.

MANAGEMENT/ANALYST INTERACTION

Experience indicates that the use of simulation modelling as a planning aid, is directly proportional to the skills of the analyst in interpreting the problem, developing a solution or methodology to solve the problem, and translating the results of that analysis into terms that managers can relate to and use in making decisions. As others have indicated, one of the most important factors is the communication between the analyst and the client manager or decision maker. Managers generally must make decisions based on incomplete knowledge, usually in a compressed time frame and often without a clear formulation of the problem. The analyst then, must reduce a "feeling" or "concern" into a quantifiable problem, this generally means a detailed understanding of the day to day operations of the enterprise is mandatory or that the analyst can communicate with the people who actually "put ore on ships" to gain that understanding. Fundamental to obtaining an acceptable solution is an appreciation of the business' objectives and any (budgetary) constraints that may preclude some possible alternatives.

Regular communication is vital. It is likely that a detailed simulation model will take some months to construct and validate, by which time the original problem may have disappeared, been solved or supplanted by more pressing matters. Rather than rely on the client, the analyst should be checking regularly to determine if he is still working on the right problem. This implies that if simulation is the chosen method to evaluate the alternatives, the model should start simple and grow more complex as the various factors are explored in consultation with the client.

Statistical and simulation jargon are of no interest to the client. Any limitations of the model and implications of variability have to be explained in clear, easy to understand terms. This is particularly true for decision logic; there will always be a set of real world circumstances that is not covered by the model that particularly concerns the client and will probably involve revision of the model logic. Since it relies on statistical variation, simulation modelling will give outputs that are themselves points in a distribution. Thus the analyst will have to undertake a number of replications of a particular run and present the findings in unambiguous terms. This can be critical when major capital decisions can rest on whether or not there is any "real" difference between alternatives.

Finally, unless the analyst is principally involved in the analysis and solution of day to day problems, there exists the likelihood that none of the proposed solutions or investigated alternatives will ever eventuate. This is particularly so for the higher level applications in strategic planning. The net result of several weeks modelling effort may be that none of the proposals is viable and that has to be accepted by the analyst.

CONCLUSIONS

The experience with simulation modelling, in particular the use of a microcomputer based language, indicates that the approach is a valuable decision aid. Suitably designed models can help quantify the effects of capital investments and changes in operating practice and greatly assist in the development of cost effective solutions to a range of problems.

The approach taken at Mt. Newman has been one of incremental development, models are developed, extended or amended as required. The overlap between the various models is seen as a benefit since results from the various models can be compared and used as a form of validation and confirmation. The differing levels of complexity also allow a range of problems to be addressed, from strategic decision making to assisting line management with day to day problems. This allows broad parameters to be defined by high level models and then used as input to fine tune solutions using more detailed models such as the stockyard model. The need for some form of overall "system" model has been canvassed however such a model is not seen as necessary at this stage since its functions are already covered by existing models. The need for some form of cost optimising model is still being addressed although the number of variables involved (data collection would be a major task) would seem to preclude such a model at present.

The continued development of simulation models is expected to involve more animation and possibly to the development of interactive systems that provide direct decision support to plant operators and controllers. With increasing computing power becoming available at lower cost, such systems could be constructed in the very near future thus providing all levels of the organisation with a tool for assessing the effects of all types of decisions.

Finally, in a closed system, such as the mining operation described here, the ability to minimise costs is easier in the sense that most, if not all, costs are internal and each part of the transport system can be analysed to determine its effect on other parts. For the more common situation (in Australia) where the transport or shipping operator is independent of the freight forwarder, it is likely that significant savings could be made if the transport task is analysed as a whole to determine the effects of the interaction between each element of the process.

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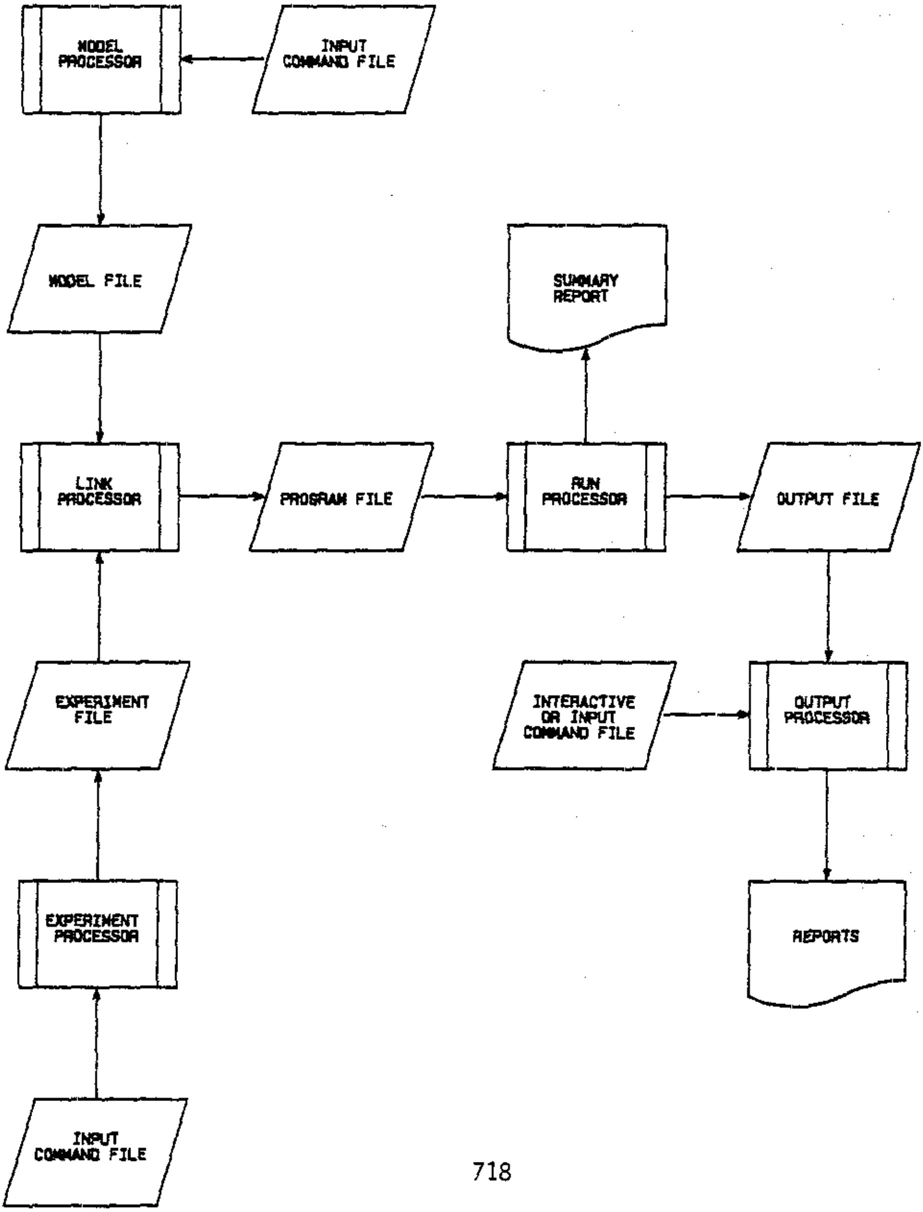
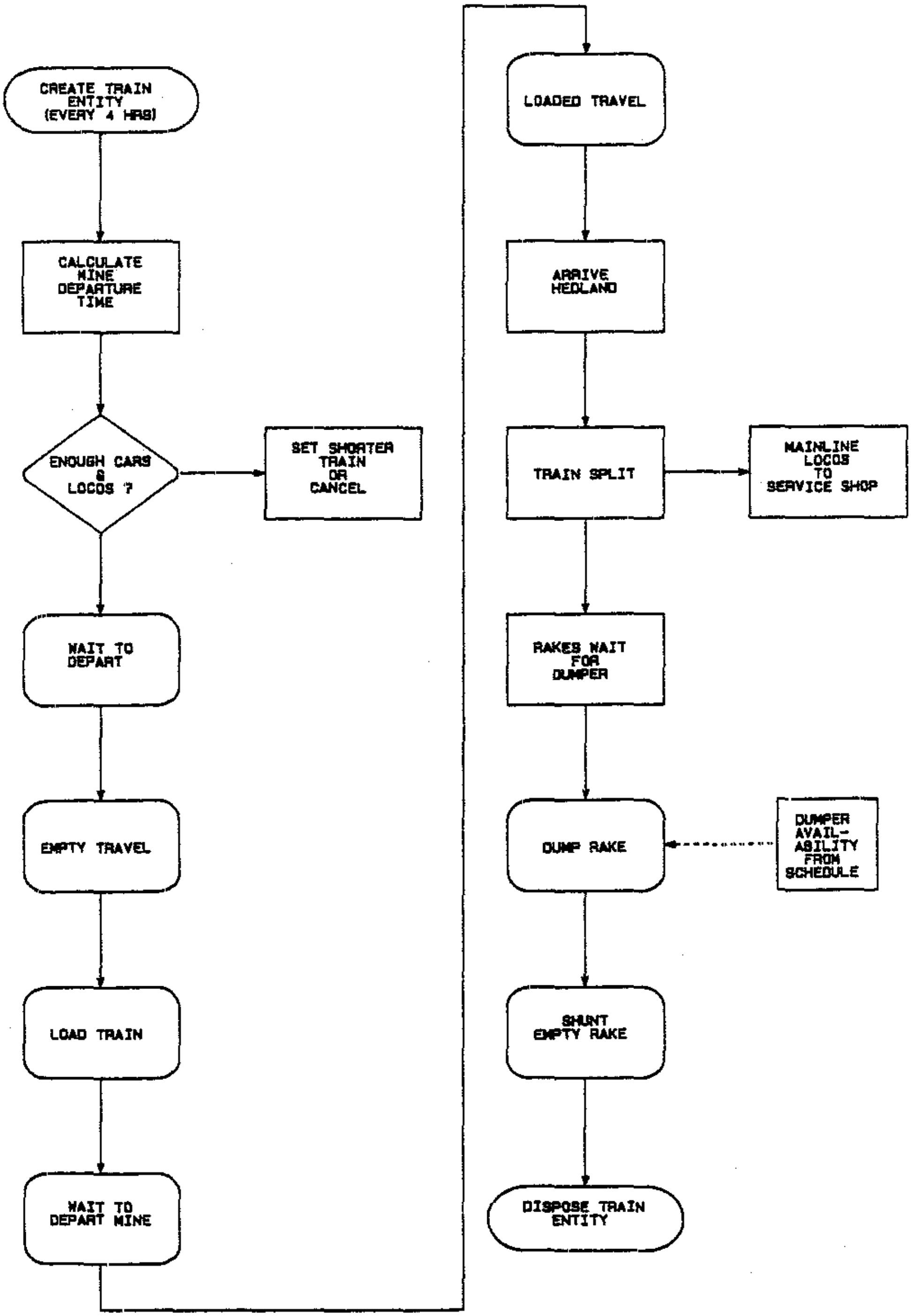
APPENDIX 1
SIMAN SOFTWARE ORGANISATION



APPENDIX 2
PORT-RAILROAD SIMULATION MODEL LOGIC (TRAIN CYCLE)



APPENDIX 3
HARBOUR MODEL ORGANISATION (SIMULA)