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IT IS ABOUT TWO DECADES since queuing models were first applied to problems of port capacity[1] and despite a growing literature their use remains limited. 'First generation' models were characteristically tentative and much of the literature contains serious errors. Some basic aspects of queuing theory are noted briefly in the following paragraphs but attention is directed mainly towards a critical examination of existing studies.

Lee[2] has suggested a simple classification of queuing models of the form A/B/C:(L/QD) in which A, B and C specify the arrival process, the service process and the number of servers respectively, L is the system capacity and QD defines the queue discipline. A and B may be selected from either of the following:

D = Deterministic (e.g. the service takes exactly 12 hours) or

M = Markovian or random. This assumes that an arrival occurs in a small interval Δ with a probability $\lambda\Delta t$. It can be shown that the number of arrivals in a given interval t is n with probability $(\lambda t)^n \exp(-\lambda t)/n!$, the Poisson density. It also follows that the time between arrivals has a density of $\lambda \exp(-\lambda x)$. λ thus represents the average number of arrivals per unit time and $1/\lambda$ the meantime between arrivals.[3]

Similarly, for the service process β is the service rate and $1/\beta$ is the meantime between services in a non-empty queue. It should be emphasized that an M process results in a large number of events clustered together as the mode is zero. This is a plausible assumption for A but quite unrealistic for B as the discharge process in a port system.

E_k = Erlangian with parameters k and β. This has a density function of $\beta(\beta x)^{k-1} \exp(-\beta x)/(k-1)!$ and mean of k/β. It can be regarded as k stages each of M with parameter β. M is thus a special case of E_k with $k = 1$. For $k > 1$ the density can be roughly described as a skewed normal distribution with non-negative values, the larger k is the closer to a normal distribution. It is the simplest mathematical model for the ship discharge process that has any realism.

GI = General Independent. This model has all the others as particular cases and includes all distributions without auto-correlation.

G = General. The same as GI except that auto-correlation is now considered.

It should be emphasized that except for the M/M/C queue all other systems result in an output process that is auto-correlated. This means that no other system including the $M/E_k/C$ system is capable of mathematical solution if the ship calls at more than one wharf. It should also be pointed out that even when there are no such complications the $M/E_k/C$ system is very cumbersome mathematically and has not been completely described for cases when C and $k > 2$. Consequently it would appear that queuing theory is appropriate when a ship discharges once only at a small group of wharves. For any larger system simulation is necessary.

Given these more general aspects of queuing models we now turn to some of the specific problems which have appeared in the literature. Three problem clusters are identified—that relating to the measurement of congestion, the problems of arrival, service and queuing times and the problem of defining the operational structure of a port.

Measuring Congestion

What appears to be an intuitively simple concept is in fact rather difficult to define and at the outset we refer briefly to some of the ways in which congestion and acceptable levels of congestion have been dealt with.

Fratar et. al[4] (1960) considered the problem of congestion in terms of what was called the 'berth occupancy pattern' —the number of vessels in port over a given period. When the number of vessels in port exceeded the number of berths available congestion resulted. In order to determine the capacity of the port a ". . . level of congestion must be established to represent the practical limit beyond which the service provided to vessels is not adequate."[5] The real problem lay therefore, in determining that level or in defining a "criterion of congestion'. This was set subjectively at 5 percent or about 18 days per year and enables 'maximum practical' berth occupancies to be assessed—29 percent for 1 berth, 38 percent for 2 berths etc.

There are a number of problems in the approach. Clearly, any arbitrary level for berth occupancy is open to debate but the more serious problem is that the criterion is, in a sense, exogeneous to the system. It gives no clear indication of how many ships queue at any one time nor how long they queue for—i.e. the queuing time distribution. Nor is any measure of costs given, either for ships or for idle berth capacity (though later papers by Plumlee[6] and Nicolaou[7] for example attempt to deal with the problem).

The 5 percent level may or may not be satisfactory in absolute terms. The

Modelling and Port Policy Decisions: The Interface of Simulation and Practice

by

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real problem is just what a 5 percent level means. Gooneratne and Buckley[8] have rightly emphasized that while the total of intervals of time when ships are seen to queue may add up to 5 percent of the time period, ships would undoubtedly queue on far more than 5 percent of the days.

Miller[9] has pointed out two further problems relating to the treatment of berth occupancy as the number of ships in port at any time. The first underlines the confusion which exists between the number of ships which arrive in any day and the number of ships in port on any day. Only if the ships arrive at random and servicing of vessels is independent of each other and the number of ships in port does the number of ships in port have a Poisson distribution. The second problem concerns the validity of the chi-squared statistic to test the hypothesis that the number of ships in port is Poisson in form.[10] The test incorrectly assumes that the number of ships in port on one day to be uncorrelated with the number on the following day.

It is apparent that a definition of an acceptable level of congestion in terms of the distribution of the number of ships in port and an exogeneously determined 'level of congestion' is unsatisfactory. A number of other papers[11] have relied on the Poisson distribution for the number of ships in port to determine acceptable congestion and the same comments are applicable to these.

Recent papers have approached the problem of congestion with a somewhat different emphasis. Of these Mettam,[12] White[13] and Gooneratne and Buckley[14] for example, stress the more direct measure of ships' delay times and evaluate port capacity in terms of some measure of queuing times and costs.

Mettam assumes a Poisson distribution of arrivals and an Erlangian $k = 2$ distribution of berth service times to define the ratio Tw/Tb (average waiting time for all ships and average berth service time). The ratio is then plotted against the average berth occupancy for a number of berths. This direct approach is useful in two ways—first it enables a clear comparison of alternatives and second it provides input data for further economic analysis and investment appraisal. Thus for example, if a ratio of $Tw/Tb = 0.1$ indicates a level of delay acceptable to users (it may or may not!) Mettam finds that equivalent berth occupancies for 10, 4, 2 and 1 berth are 76, 51, 29 and 9 percent respectively. However, for specialised single berth terminals Mettam and Nicolaou agree that an acceptable range of berth occupancies is 30 to 40 percent.

In a recent paper White[15] again highlights the problem of an arbitrary congestion level. The analysis rests on the calculations of the number of ships in a queue (and the associated costs). These values are then graphed against berth occupancy and comparative values can be read off. Further examination of the relationship between throughput, costs and berth occupancies suggests that a maximum acceptable berth occupancy for a single berth (in this instance a coal loader) is given theoretically at 57 percent and at 70 percent by an empirically modified relationship!

Clearly, when estimates of maximum berth occupancy for a single terminal vary between 29 percent (Fratar et. al) and 70 percent (White) the definition of acceptable congestion requires extremely careful evaluation and remains an important research theme.

Somewhat subjective estimates of occupancy appear to be a less than satisfactory basis for determining the optimal number of berths in a port. The direct predictions of waiting times and delays offer a more fruitful approach, particularly when these values are used as inputs for estimates of costs against investments. Thus far, studies of this kind using mathematical queuing models (as opposed to simulation studies) are few. Plumlee[16] and Nicolaou[17] for example, attempt to trade off ship idle time and berth idle time to define the optimal number of berths; Eddison and

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Owen[18] and others use a minimization of the costs of total annual ship time in port against investment costs. More recently Buckley and Gooneratne[19] consider the problem of optimal scheduling of investments under conditions of increasing traffic congestion and trade off discounted congestion costs against discounted capital costs.

The problem of the optimization of investments[20] is clearly a difficult and complex area of analysis and it must be admitted that it remains a high-priority research area. Moreover its complexity leads almost inevitably to a systems analytic approach rather than the more restrictive mathematical queuing model analysis.

Time Distributions and Waiting Time Predictions

The Poisson process, because of its mathematical tractability and its ease of application to empirical data, has been widely and to some extent uncritically adopted as an adequate description of the arrival process of ships. Nonetheless, numerous studies have confirmed that arrival distributions are Poisson in form —Omtvedt[21] for Haifa and other ports, Da Silva[22] for Lisbon, Nicolaou[23] for the major ports of Cyprus, Jones and Blunden[24] for Bangkok and UNCTAD for Casablanca.[25] Recent research has suggested however, that the uncritical acceptance of the simple, completely random pattern of inter-arrival times, at least for bulk loading installations, leads to serious errors in the prediction of delay indicators.

Gooneratne and Buckley[26] gave evidence of the possibility of congestion dependency in the ship arrival rate in their analysis of bulk ship data for the Port Kembla and showed that a 'discouragement' model suggested by Cox and Smith[27] which assumes the arrival rate $\lambda(n)$ to be inversely related to the number n of ships in the queuing system according to $\lambda n = \lambda(o)/(n + 1)$ gives better prediction of ship delays than conventional models using Poisson arrivals. It seems apparent that random arrival rates may be influenced by control exerted over vessel arrivals when congestion is actual or likely, though the extent to which this occurs requires further investigation. Nor has any study examined the problem in relation to general cargo patterns rather than single channel bulk installations.

Service time distributions are influenced by many factors and may not conform to a simple negative exponential distribution. Most studies have found however that Erlangian distributions may be used as approximations—thus Mettam finds a $k = 2$ curve satisfactory, Jones and Blunden a $k = 3$ curve etc.

While the specification of a single distribution of service times implies a mean service rate unaffected by congestion, in ongoing research, Gooneratne[28] finds, as anticipated by Chapon[29] that ship congestion (the number of ships in port) at several Australian bulk loading ports tends to have a speeding up effect on the effective ship servicing rates.

The form of the curve is rather less important, however, than a definition of what constitutes service time. Few studies define it carefully and no study has in fact tested the sensitivity of its measurement. Whether or not different measurements are of real significance thus remains to be tested. Mettam specifies service times as ". . . the time when the berth is effectively occupied by each ship including transit time between the berth and the point where an incoming ship will have to pass an outgoing ship."[30] Gooneratne and Buckley examine the definition closely and follow Lee's block-time definition (". . . the interval that elapses between the instant at which one customer's service time begins and that at which the service time of the next customer begins, when this second customer has been in a queue waiting for service.")[31] Thus they define an 'effective service time' to include travel to and from the berth together with the idle time at the head of the queue when the berth is vacant and argue that such a definition is valid and necessary for the application of queuing theory.

A first-come first-served queue discipline appears a reasonable approximation for most port situations and observed violations are few.

Definitions of the arrival and service time distributions enable the further calculation of queuing and delay times. Unfortunately few studies have in fact tested predicted waiting times against actual, observed values though Jones and Blunden, for example, give the 'criterion for acceptance' of their two models as the ". . . reasonable agreement achieved between the computed and observed values of waiting time and of the average number of ships in the queue . .."[32]

In 1969 Agerschou and Korsgaard[33] noted the problem of senstivity of theoretical waiting times to deviations of actual arrival and service time distributions. Since that time research at the port of Port Kembla and at Australian bulk loading ports has provided evidence of serious discrepancies between observed and predicted waiting times.

For bulk ships at Port Kembla, Gooneratne and Buckley[34] found that agreement between predicted and observed values of delay depended on the traffic intensity, ρ, (or berth utilization) involved. While the Poisson arrivals, Erlang $k = 2$ modeloverpredicted delays at a single berth terminal for all values of ρ, the M/M/1 model with $\lambda(n) = \lambda o/(n + 1)$ discouragement gave satisfactory predictions for values of $\rho < 0.5$. For values of $\rho > 0.5$ the observations were falling between the predictions from these two models.

In more recent research Gooneratne[35] finds that classical models with Poisson arrivals and constant mean ship arrival and service rates seriously overestimate congestion at bulk loading ports. Gooneratne and Buckley suggest a variety of models with varying forms of congestion dependence in the arrival which appear to give better predictions and Gooneratne also suggests the inclusion of sensitivity of the service rate to congestion in ship queuing models for bulk ports.

White has also noted that the timing of an additional coal loader in the port of Port Kembla is particularly sensitive to the predicted values of queue length.[36] Computed semi-empirical values for queue length, modified on the basis of observed writing times, are about half the theoretical values. Calculations for the general cargo berths in the port, in contrast to those for the bulk loader, exceed the theoretical values.

It is apparent that queuing studies generally have adopted a too-simplistic approach to time distributions and rather than having 'arrived' the state of the art is very much in a state of flux.

Defining the Operational Structure of a Port

The analysis of queuing systems is, as we have pointed out above, dependent on the time-relationships within a port system. Except as it influences time distributions the spatial pattern or physical layout of the port has not been considered relevant. Spatial location of berths is not in fact, important: what is significant however, is the pattern of linkages among the berths defining operational sub-systems within the total port system. It is the way which berths function as operational units rather than their physical grouping, which is pertinent to queuing analysis. Mettam made the problem explicit in his discussion of Nicolaou's paper[37] and pointed to the variations in berth occupancy with varying number of berths.

The need to rationalize intra-port shipping movements and to minimize port turnround time for increasingly specialised, high-cost carriers has been responsible, particularly through the 1960's, for the gradual breakdown of the port system into a set of operational subsystems. As well as this it is probable that individual ports will have operational patterns which are specific to the cargo mix and possibly to trade patterns. Oil terminals and some bulk terminals are readily observed to operate as independent or quasi-independent elements within the morphology. General cargo sub-systems are usually much less apparent. The problem then, is to identify the operational sub-systems.

Ships move from berth to berth within a port system and each ship will trace out a set of sequential linkages. The sum of all vessel movements between berths will indicate the intensity of interdependence between berths. The port system may in fact be represented as a stochastic matrix and transition probabilities computed. The first-step, second-step and n-th step matrices for all ships may also be computed to indicate staged movement patterns. Dominant sequences may be listed computationally for all ships and/or for relevant groups of ships.

The problem of grouping or regionalizing elements on the basis of linkage patterns has been examined by geographers in the concept of a functional region—one in which the elements have greater interaction between each other than with outside elements. Transaction matrices whose entry values represent the extent of interaction between the ith and jth locations have been used as the basis for factor analytic procedures for deriving functional regions. Where direct factor analysis[38] is used, factor loadings indicate functional groups. Goddard,[39] using common factor analysis and transforming the interaction matrix into a correlation matrix, groups elements on the basis of their similarity of origins and destinations. Brown and Holmes[40] note the inadequacy of the method to define functional regions.

All movements between all i's and all j's will be shown in the transaction matrix. What does not appear however, is any indication of the movement sequences which are in fact critical in the structuring of functional or operational patterns or clusters. Ships move about in port. Ship 1 moves from Berth 1 to Berth 4, ship 2 from Berth 4 to Berth 3. No link exists between Berth 2 and Berth 3 but because both ships visit Berth 4 the three (3) berths may in fact be considered to be part of the same operational group.

In the spatial literature the need to evaluate these so-called 'indirect links' to adequately define spatial structure has recently led to the use of Markov chain analysis.[41] The interaction matrix is regarded as a regular Markov chain and the matrix of transition probabilities defines the probability of movement from i to j. The matrix of mean first passage times (MFPT) gives the average number of steps required to reach j from i and considers both direct and indirect links. The matrix may then be subjected to a multivariate grouping algorithm or to direct factor analysis to define functional clusters.

Unfortunately the problem of defining the operational subsystems within ports is not completely analogous to functional distance analysis on at least two counts. The first is that the port system may be viewed as an absorbing Markov chain in which the entry/exit point is the absorbing state. It is not yet clear whether the functional distance approach can be used for absorbing chains as well as for regular chains. The second point arises from the fact that indirect links derived in the MFPT matrix are in fact 'contrived' in the sense that they are not actual movement sequences.

Moreover movement of ships within ports is almost certainly non-Markovian. If the port system was operating as a Markov chain the ship on entering the port would select one of a set of berths that would be quite independent of the state of the system. Thus it would not depend on the size of the queue from which it came or the presence of other ships in the system except that they were occupying berths. Having completed service at a particular berth it would then select another berth in accordance with probabilities only determined by its current berth and not affected by any previous sequence. Such a Markov chain would result in a great simplification of the port model. Unfortunately it is certainly invalid for the system considered. Firstly, the selection of a berth was influenced by the other ships present in that the berth with the maximum crane capacity was always preferred. Also having selected a berth the movement of a ship to the next berth was always very sensitive to the history of berth visits it had already made as well as to the state of its cargo at that particular instant.

Further research[42] into the definition of operational sub-systems is proceeding and it appears that transition probability matrices together with computationally derived dominant sequence patterns may provide the simplest method.

SIMULATING A QUEUING SYSTEM —AN EXAMPLE

Mathematical queuing models are at best partial models. The limiting assumptions are restrictive and departures from the simpler exponential distributions of service times for example, lead to relatively complex mathematics. Simulation modelling lacks mathematical elegance but achieves a high degree of realism with its only real limitation the cost of programming and running on the computer.

The number of simulation studies in the literature is extremely small. Several papers[43] have been concerned with the operations of bulk systems which, generally, are somewhat less complex than simulations of general cargo systems. In 1969 Korsgaard[44] reported a simulation model comprising four submodels — carrier turn-around, cargo handling, storage and working days and hours models. More recently, Hansen[45] has examined port capacity in terms of quay length and cargo handling equipment and tested the sensitivity of a number of parameters to changes within the system. The most detailed and sophisticated model reported to date however, is that developed for a general cargo system by the United Nations Conference on Trade and Development.[46] In that model the simulation reproduced a series of operational subsystems (e.g. towage, signals, pilotage etc.) each with a varying technical standard and was carried out to establish times consumed by ships and cargo in the port system. These were then used as input for an investment optimization programme.

The present study attempts to simulate the queuing system specific to the port of Port Kembla in N.S.W. This is not to say that the model is not able to be generalised, only that some subsystems which appear to be unimportant in the specific case have been omitted. Both bulk and general cargo systems are included in the simulation and account is taken of the sequential movements of shipping in the port. The following section briefly notes some of the characteristics of the port and the input data for the simulation.

The Port System

In 1971-72 the port of Port Kembla handled 11.9 million tons of cargo ranking it after Sydney (17.8 million) and Newcastle (14.8 million)[47] among the N.S.W. ports and sixth in Australia. It is heavily oriented to the high volume, dry bulk trades of coal, coke and ore and to the movement of iron and steel products. Table I lists the major flows and clearly underlines the dependence of the port on a narrow range of commodities.

This dependence is further reflected in the simplicity of the port morphology (Figure 1). The port consists of an artificially enclosed Outer Harbour and a dredged Inner Harbour with a total

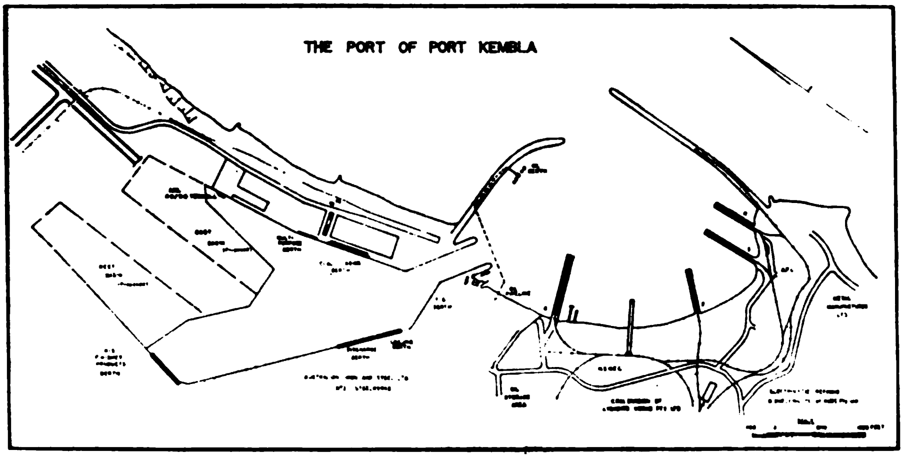

TABLE I

Trade Flows, Port of Port Kembla, 1971-72*

MAJOR COMMODITIES (000's tons)

Interstate Trade	
Imports	
Ironstone	4.386
Oil	324
Iron and Steel	314
Limesand	205
Dolomite	168
Sulphuric Acid	143
Foreign Trade	
Imports	
Phosphate Rock	117
Iron and Steel	88
Limestone	64
Oil	57
Exports	
Iron and Steel products	600
Coal	548
Coke	454
Exports	
Coal	3.079
Iron and Steel products	362

*Source: Abstracted from Port Statistics 1972-1973 Maritime Services Board, Sydney, 1972, pp. 28-30.

area of approximately 480 acres. There are five (5) wharves in the Outer Harbour with berthing spaces as shown on the diagram. Only seven (7) berths are available for general purpose handling with No. 2 jetty under long-term lease to Australian Iron and Steel (A.I. & S.) and No. 5 jetty used as an oil berth. In the Inner Harbour there are six (6) berths including the coal loader and a load and discharge berth operated by A.I. & S.

The port has grown rapidly in the 1962-1972 period with total tonnages increasing from 6.9 million tons in 1962 to 11.9 million tons in 1972. Exports have more than doubled from 2.07 to 5.3 million tons over the period, reflecting growth in coal exports. Imports have grown less dramatically from 4.9 to 6.6 million tons and in 1971-72 the balance between import and export flows was closer than at any previous time. This growth has placed pressure on port facilities, particularly on the bulk loading installations but also on the berths handling iron and steel products as general cargo.

Basic data for the simulation have been developed from Vessel Turnaround Cards which are compiled for each vessel entering port by the Maritime Services Board of N.S.W. Thirty-six (36) variables were coded for each ship describing characteristics of the ship, components of vessel time in port, berth characteristics and ship movement sequences. Ship characteristics included DWT, length, draft, beam and cargo loaded and unloaded. Movement sequences for each ship listed the pattern of berth to berth movement and the timing involved. Time variables referred to the gross and net working times, turnround and idle times, delay times for weather, repairs etc. Data for berth characteristics included cargo loaded and unloaded, working times, idle times etc. Additional variables describing the cargo handling capacity were coded from other sources.

Several detailed data processing programmes[48] were developed to provide statistical descriptions of the operational characteristics of the port as well as to provide input to the simulation programme. These latter included for example, inter-arrival distributions for sets of vessels defined by cargo type, queue behaviour at each berth throughout the year, hourly and weekly arrival patterns for different ship types and so on.

The Simulation Model[49]

The model is built up as follows. The

structure of the numerous components is based on a description of the physical port system and includes such information as the layout of berths, length of wharves and depth alongside, crane capacities etc. The state of the system is described in terms of the utilisation of these various components by ships e.g. whether a berth is occupied, whether a ship is in transit from one wharf to another, whether a crane is being used etc.

To write the simulation program all the components in the system are defined as either permanent entities such as wharves which remain unchanged throughout the simulation or temporary entities such as ships which come into the system (are CREATED) and then leave the system (are DESTROYED). Events are then defined which show how the state of the various components may change. These are in fact represented by sub-routines in the program. An early version of the program will be described to illustrate some of the detail. The program was written in SIMSCRIPT II for an IBM 360/50 machine. The SIMSCRIPT II system, as well as serving as a normal compiler, also has a timing routine which takes control of the program at run time. It also possesses extremely high level list processing capabilities which enable the treatment of the queue to be carried out in a very elegant fashion.

Firstly the wharves are treated as permanent entities which enables simple references to be made to their length, depth etc. such as LENGTH (WHARF). Each wharf is then allocated a set or queue of berths. The berths are represented as temporary entities and have attributes such as L. DEP which records the time of last departure of a ship. When a ship can be berthed the appropriate berth is removed from the set of berths for that wharf and this berth is then filed back in the set when the ship is unloaded. Having berths in a queue makes it easy to determine when a wharf has an unoccupied berth and also allows other berths to be added at any later stage for experimental work. Ship is also defined as a temporary entity with attributes such as TYPE, CARGO, SIZE etc. The main queue for all types of ships that cannot be berthed is called Q.

The state of the system is described by two main events called ARIV (arrival of a ship) and DEP (departure of a ship). These are special sub-routines which are under the control of the timing routine.

Having initialised all data sets by entering lengths etc. into wharves a ship is created in the main program and ARIV is scheduled to occur. Then control is passed to the timing routine. It looks at the calendar of events and sees that ARIV is the only event scheduled. It then passes control to ARIV where it has a reference to ship at which stage it is able to determine from the types and specifications of the ship whether a suitable berth is available from which it can calculate the time at which the ship finishes unloading. It then schedules ENSER to occur at this time and schedules another ARIV and creates another SHIP for the ARIV. If there were no berths available it would queue the SHIP in Q and then at the next ARIV it would check whether a berth had become vacant. At the conclusion of ARIV, control is then passed back to the timing routine. The timing routine would then transfer control back to another ARIV or ENSER depending on which was to occur first.

Assume that the next event was ENSER. We can follow this through from the listing below:

```
EVENT DEP SAVING THE EVENT NOTICE . . . . . . .
        DEFINE Z AS AN ALPHA VARIABLE.
        LET SHIP = SHIP.NO(DEP)
“         REMOVE THE SHIP FROM THE WHARF.
        DESTROY THIS DEP.
        LET WHARF = WHARF.NO(SHIP)
        LET BERTH = BERTH.NO(SHIP)
        LET LENGTH(WHARF) = LENGTH(WHARF) + SIZE(SHIP)
        FILE BERTH IN BERTHS(WHARF)
        SKIP 3 LINES.
        PRINT 2 LINES WITH SHIP, TYPE(SHIP), WHARF,
          LENGTH(WHARF)
          BERTH, N.BERTHS(WHARF) AND TIME.V THUS
        DEPARTURE OF SHIP ........................(........) FROM WHARF ........
          (LENGTH NOW ........................)
          BERTH ........................(NOW ........ FREE BERTHS) AT ....................
        IF TYPE(SHIP) = “ORS1” LET TYPE(SHIP) = “ORS2”
          SCHEDULE OF ARIV NEXT.
          LET SHIP.NO(ARIV) = SHIP.
          GO TO SEARCH ELSE
```

```
         DESTROY THIS SHIP.                                       17
"           ARE THERE ANY SHIPS WAITING IN THE QUEUE.             18
"           SEARCH THE QUEUE TO SEE IF A WAITING SHIP WILL
               FIT FREE BERTH.                                    19
   'SEARCH' FOR EACH SHIP IN Q DO                                 20
            IF TYPE(SHIP) = ORS1" LET Z = "ORE" GO TO CHECK ELSE  21
            IF TYPE(SHIP) = ORS2" LET Z = "STEE" GO TO CHECK ELSE 22
            LET Z = TYPE(SHIP)                                    23
   'CHECK' IF CHECK.SHIP(Z) = O GO TO DENTER ELSE                 24
            LOOP                                                  25
"           NO SHIP WILL FIT INTO THE BERTH.                      26
         PRINT 1 LINE WITH BERTH, WHARF THUS                      27
         BERTH NUMBER ........................ WHARF ........ IS NOW EMPTY—
            NO SHIP WOULD FIT
         RETURN                                                   28
"           SHIP IN THE QUEUE WILL FIT SO PUT IN THE BERTH.       29
   'DENTER' REMOVE THIS SHIP FROM Q.                              30
         LET Q.TIME = Q.TIME + (TIME.V — ARIV.T(SHIP))            31
         PRINT 1 LINE WITH Q.TIME AND N.Q AS FOLLOWS              32
         TOTAL QUEUE TIME IS NOW ........................ N.Q. = ................
         CALL ENTER.SHIP                                          33
            IF N.BERTHS(WHARF) = O GO TO SEARCH ELSE              34
            RETURN.                                               35
END . . . . . . . .                                               36
```

As can be seen, the SIMSCRIPT II language closely resembles English and is instantly readable (though unfortunately, not instantly writable!) Referring to the line numbers on the right, it will be seen that lines 4, 18, 19, 26 and 29 with double quotation marks are comments and not processed by the compiler. It can be seen that ship which has been scheduled for DEP has its reference available in SHIP.NO(DEP) and this is made equal to SHIP as a shorter title. Line 5 is for book-keeping. Lines 6 and 7 give short names for the identity numbers of the wharf and berth for a particular ship. Line 8 updates the length of wharf available for this particular wharf. Line 9 makes this berth available to the system by filing it back in the set of berths for this wharf. Lines 10 to 12 output information for checking. Line 13 codes the sequence for the last visit to a wharf for this particular type of ship. Line 14 ensures that an arrival will occur immediately, thus ensuring that this ship will be put in an appropriate berth or into the queue. Line 15 identifies the ship number associated with the arrival. The search routine checks the type of ship and then through the sub-routine CHECK-SHIP decides whether there is sufficient length of wharf and if so files the ship from the queue into the appropriate berth.

This brief outline is sufficient to suggest that the simulation is capable of handling rather fine detail in the port system. Stage I of the research programme has focussed on the queuing system in the port and the output from this gives statistics on queuing and total system mean times together with individual berth occupancy times. It also provides full sequential statistics on serial visits to berths for each type of general cargo ship.

Stage II of the simulation, presently being developed, includes all relevant costs such as total daily ship costs, operating and capital costs of wharves. Output from this analysis enables the possibility of comparison and assessment of a variety of investment alternatives as well as providing insights into the formulation of a simplified mathematical model.

MODELLING AND POLICY

Models are abstractions of the real world and as such seek to define specific, often limited relationships in a search for underlying structure. Mathematical queuing models and simulation models of queuing systems in ports are no exceptions—basic premises often assume away the grubbier parts of reality for mathematical nicety. The decision-taker cannot be so naive and is well aware of the operational complexities of the port system.

Is there then, a valid role for model-building in the policy making process?

The review of the literature in the first part of the paper clearly indicates some fairly serious problems which have arisen in numerous studies. It also suggests that modelling is still very much in a state of flux and a good deal of experimental work remains. Nonetheless, both the process of model-building and the model itself can no longer be regarded as 'optional extras' in the decision-making process. The precision required in specifying and defining relationships and the rigour of logical thinking and inference inevitably lead to a more accurate understanding of port operations and the planning process. From the model, whether it be a mathematical queuing model or preferably a more powerful simulation model, should emerge not only an important set of parameters and statistical distributions (which are in themselves extremely valuable decision inputs) but also a set of investment alternatives ranked on the basis of pre-determined criteria.

What is further apparent is the need for model formulation to be a normal part of the planning process to be carried on by a specialized team of researchers, including an operations research specialist. Most boardrooms appear yet to be convinced of this—but it is the constant evaluation of model against reality, theory in the light of practice, that leads to effective policy-making.

FOOTNOTES

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16 Plumlee, C. H., op. cit.

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