A NEW AVAILABILITY MODEL

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Introduction

This article is concerned with a Ship Availability Model as developed under a contract from Director General Ships by the British Aerospace (Dynamics Group), Filton. The article is aimed at those civilian and naval officers whose responsibilities or interests lie in the fields of reliability, upkeep, and associated disciplines in the naval context, and it will be assumed that such readers are familiar with standard availability concepts and theory. The objective is to give sufficient details of the model to enable potential users to understand what the facility can offer them and how to put it to use.

The general modelling method developed is applicable to any engineering system or ship; only the design information, data, and operating profile or 'mission' make the eventual model specific to a particular application. It so happened that the Hunt Class mine countermeasures vessel (MCMV) was modelled contemporarily with the development of the modelling method, and the whole exercise was funded and managed through the MCMV project. Consequently the MCMV will feature strongly in references made to information and results produced at present. Since this vessel involves the use of a mobile, land-based forward support unit (FSU), the FSU will feature in some maintenance references.

Background

An availability model is a set of relationships which describe the behaviour of a ship (or other engineering complex) in the availability field. These relationships, which are actually logic equations, depend upon the nature of availability, equipment interdependencies, failure and repair data of equipments, the times during typical mission activities that the equipments are at risk, typical mission profiles and activity durations, onboard repair facilities, the availability of shore-based support, and so on. Equations of such complexity and number can be dealt with only by a computer. Having solved the equations by this means the results can be printed out in a form best suited to the needs of the customer. This process is illustrated schematically in FIG. 1. The computer is programmed to solve appropriate equations, using ship and mission data, printing out the results as availability predictions.

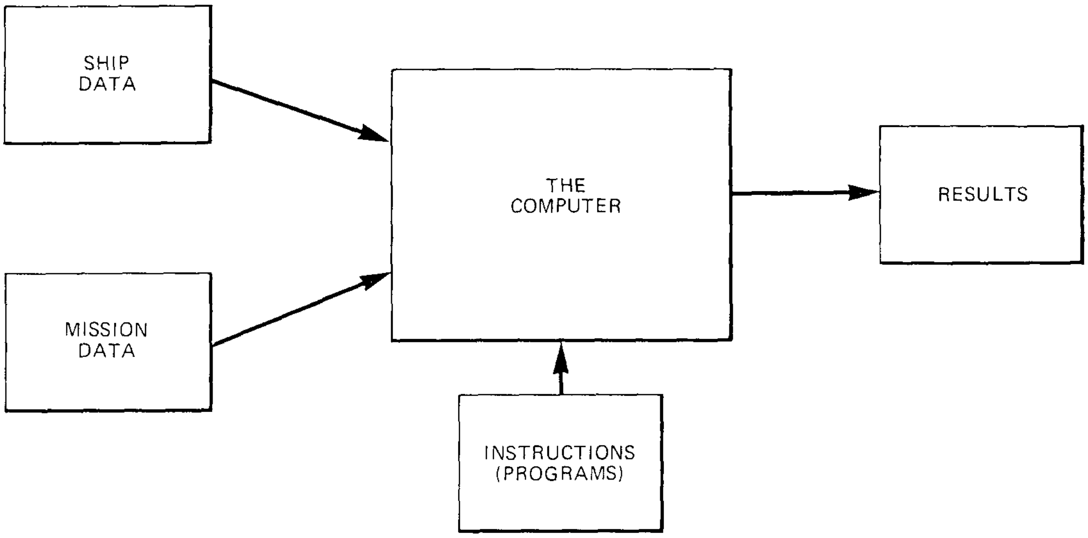

FIG. 1—THE BASIC MODEL

The new availability model follows the style set by its immediate predecessors in that the ship systems are modelled in the form of Seagoing Characteristics, Fighting Capabilities and Common Support Services. Initial attempts at this were made by Lieutenant-Commander Sherwin and Lieutenant Davies, R.N. of the Ship Availability and Usage Working Party (SAUWP) at SMA between 1969 and 1971 with their *Leander* model. This established the principles of dividing the ship into Seagoing Characteristics and Fighting Capabilities and of displaying the equipment relationships by an adaptation of the Functionally Identified Maintenance System (FIMS) in the form of Dependency Charts.

Characteristics are those seagoing features which are common to all ships, e.g. flotation, manoeuvrability, navigation. Capabilities are those fighting features which vary from ship to ship, e.g. destroying airborne targets, destroying underwater targets, mine sweeping, etc. The Common Support Services are those features like electrical power and sea-water systems which support both Characteristics and Capabilities.

The *Leander* model was followed by Vosper Thornycroft producing a model in the *Leander* form for the Type 21 frigate. Then between 1970 and 1971 a combined BAC/Rolls-Royce/Vickers/Y-ARD team carried out a Dependability study on the Type 42 destroyer, and subsequently BAC were tasked with applying the *Leander* modelling procedures to that ship.

All these 'models' had consisted of no more than a set of dependency charts and contained little or no reliability and repair data. Dependency charts, being a comprehensive form of design disclosure, permitted an appraisal to be made of the equipment relationships, and an appreciation of the equipment combinations on which the availability of each Characteristic and Capability depended.

It was recognized that the design disclosure aspects of the dependency charts were useful in their own right and, in fact, on the Type 42 destroyer had led to some design changes, but if real analytical and predictive use were to be made of modelling two things had to happen. Firstly, the model had to be computerized—it would not be possible to manipulate the whole suite of charts and the multitude of equipment combinations contained therein without the aid of Automatic Data Processing (ADP). Secondly, the provision of failure and repair data had not really been tackled. The *Leander* model had been content to demonstrate the availability theory, with data acknowledged to be inadequate, and the Type 21 frigate and 42 destroyer models had little relevant fleet data and no effort or money allocated to do any prediction work.

When it was decided to produce an availability model of the MCMV, only a fully computerized version was contemplated. The task commenced in late 1973 and the MCMV model was commissioned for use in August 1977. It follows that the general computer modelling facility is also available to be applied to any ship or system, provided only that the 'paper model' is first produced.

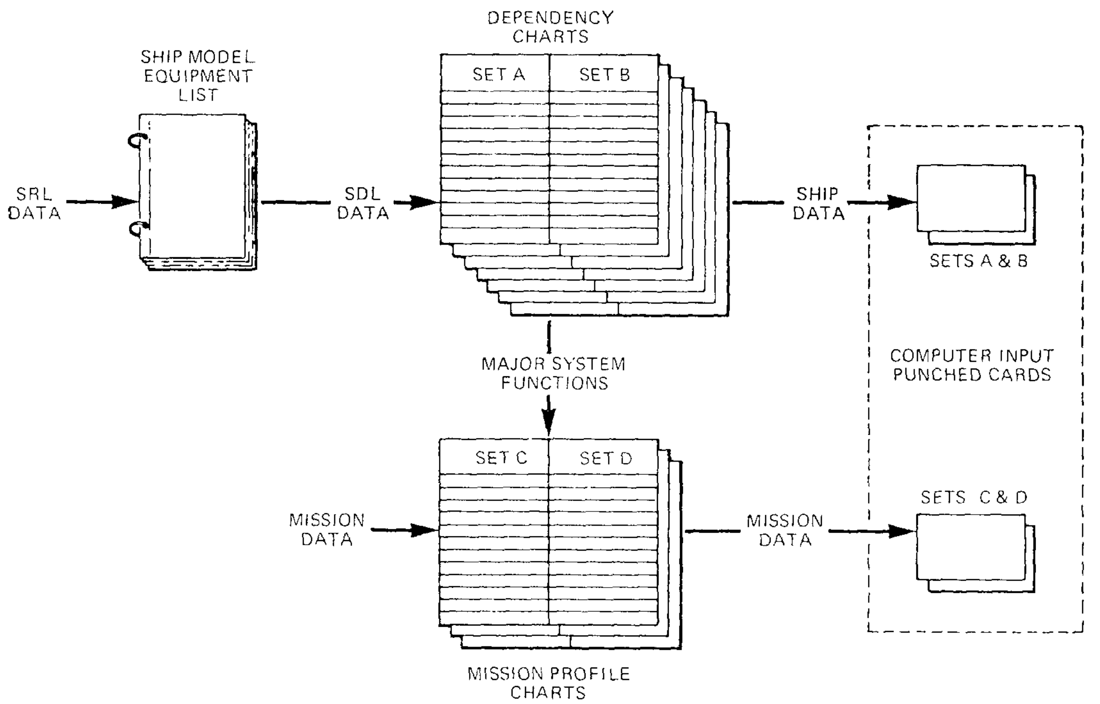

FIG. 2—THE 'PAPER MODEL'

The Paper Model

This comprises system design information, equipment data, and limited ship operational information which is recorded on Dependency and Mission-Profile Charts and in a Ship Model Equipment List (SMEL) as illustrated in FIG. 2. The essential features of these documents are covered in following paragraphs.

Dependency Charts

Each of the seagoing characteristics, fighting capabilities and common support services, hereafter referred to collectively as characteristics, is modelled on a single dependency chart. The dependency chart shows the dependence of the particular characteristic on functions generated by equipments or systems modelled at the so-called Ship Definition Level (SDL) and the term SDL is used for such equipments and systems. The SDL was originally chosen as the chart building block because it fitted in with the former Ship Upkeep Information System (SUIS) which offered certain advantages. Those advantages have now decreased but even so the SDL remains a very convenient choice and almost invariably matches the equipment which would have been chosen independently. Choosing at too low a level over-complicates the model and at too high a level forfeits valuable information potential. Dependency charts can accurately depict redundancy arrangements with identification of prime and standby equipments active or passive.

The complete set of availability dependency charts for a ship represents a collection of statements which completely describe that ship. For the MCMV, 24 charts are used containing a total of 114 major system functions (defined below) derived from 480 SDL equipments.

The charts culminate in the Major System Functions mentioned above and in Availability Levels. A major system function is the function level at which a Ship Mission Profile is described. Typical examples are: 440-V electrical supply; two-pump automatic steering; coastal navigation. The availability levels of Full, Acceptable, Degraded and Minimum have the following meanings:

Full —all systems and standby equipment up.

Acceptable—some minor systems or standby equipment down (the ship would go to sea in this state).

Degraded —some important systems down (the ship would not go to sea in this state but might stay on mission).

Minimum —serious loss of seagoing and fighting capabilities, just capable of remaining afloat or of getting home unaided.

These availability levels are not themselves part of the model hierarchy. They are basically equipment head counts introduced in the *Leander* model and of interest for cost-collection purposes; but in the procurement phase, for example, they would seem to be a useful indicator of the vessels operational value. Such information might well be used by senior procurement managers and the Naval Operational Requirements staff.

The availability dependency charts have been developed to include failure and repair data and various control parameters. A major development is that the chart is now also a computer input form which can be taken by a punched-card operator and entered into the computer. This has the additional advantage that the computer can check the drawing for constructional errors and reproduce the chart as a print-out.

Each chart is 160 columns wide and 121 rows deep per sheet and more than one sheet can be used per characteristic, if required, up to a limit of four. The right-hand 80 columns are used to list the items of hardware (SDLs) associated with the particular characteristic. These items can also be grouped according to function within the characteristic to which the chart is dedicated. Against each SDL, in the appropriate columns, are entered: reliability data, repair data, repairability-at-sea factor, the time-at-risk basis (running, calender, or mission time), time-at-risk factor, and similar information. The left-hand half of the chart is taken up by dependency logic mapping. Standardized symbology is used to link together those SDLs which make up a system function. Since the model deals in system functions rather than SDLs, beneath each SDL is entered its function (a minor system function) with a code number starting with the letter 'A'. Hence these are referred to as 'A-level functions'. Other functions are 'major system functions', 'demanded functions', and 'input/output minor system functions'. Demanded functions represent stand-by equipments which are called up during certain critical activities although their availability does not directly influence the performance of the activity in question. Input functions are those inputs from other charts necessary to the functioning of the relevant dependency chart, and appear at the top of the chart. Output functions are those leaving the chart and going to other charts; they leave at the bottom. Input/output functions are always minor system functions whose code number does not start with an 'A', to distinguish them from SDL functions. Major system functions are transferred as required to Mission-Profile Charts (see below). To complete a dependency chart, there is a set of headings and a title block and the identification numbers of the sets of computer input cards.

The rules for compiling dependency charts are contained in Volume 1, part 2 of the three volume '*Ship Availability Modelling Handbook*'.

Mission Profile Charts

The charting concept described above has been applied to another type of chart called the Mission Profile Chart. On this, any mission required to be modelled is described as a series of activities and each activity calls up the major system functions on which it depends, identifying the availability dependency charts on which they appear. Standby major system functions can be called into readiness during an activity although not actually being used except when the prime function is not available. This aspect should not be confused with standby arrangements within a major system function which are depicted on the dependency chart.

The MCMV has three mission profile charts so far—mine hunting, mine sweeping, and peacetime passage—each agreed with the appropriate operational experts when compiled and revised.

This approach of using a sequence of mission activities enables equipment to be called up for an appropriate period *of* time at the appropriate period *in* time. This contrasts with the more usual capability of calling up equipment for a total likely operating period within a mission, which precludes the generation of within-mission data. Properly sequenced and typical activities are essential for sequential state and simulation investigations.

The mission profile chart is also a computer input form and is similar in layout, appearance and size to the dependency chart. The right-hand side of each chart is used to list those activities making up a mission, such as 'leave harbour', 'general passage', etc. and those major system or demanded system functions which are employed during the mission. The functions are entered at the top of the chart and the activities, in time sequence, below. Other adjacent columns contain information on: activity duration; activity class (either primary or secondary); the next activity should the present activity be successful; the next activity should the current one fail; code letters indicating what to do if the activity fails, whether repairs are allowed in the activity or not, and similar information. No information is required to be entered against functions. The left-hand side of the chart depicts the relationship between functions and mission activities using a simplified form of the symbology used on dependency charts. Again the charts are completed by headings, title blocks, and the identification numbers of the sets of computer input cards.

The rules for compiling mission profile charts are contained in Volume 1, part 2, of the *Ship Availability Modelling Handbook*.

Ship Model Equipment List

The SDL data entered on the right-hand side of dependency charts derives from a more basic data record called the Ship Model Equipment List (SMEL). SDLs can be broken down into items at Ship Reporting Level, termed SRLs. For each availability dependency chart, the SMEL lists every SDL and its constituent SRL equipments together with all the relevant failure and repair data. The SMEL can be regarded as the foundation of the paper model, and as a very useful facility for extending dependency modelling down to ship reporting level without excessive complication of the charts. The compilation of the SMEL represents the major data gathering exercise for any ship, which for MCMV involved completion of seventy-two tables.

The rules for compiling the ship model equipment list are to be found in Volume 1, part 3, of the *Ship Availability Modelling Handbook.*

Coding Sheets

To complete the paper work, if not strictly the paper model, reference is made to Coding Sheets. One of these is truly of the nature of the paper model being in the form of a Repair Schedule giving the repair policy and capability for each SDL. In the main, however, coding sheets are more to do with the computer model, being the manual compilation of information for program control cards, to select the type of computer facility and the desired output information.

The rules for compiling coding sheets are contained in Volume 1, part 4 of the *Ship Availability Modelling Handbook.*

Design Record

The paper model which has been described is an essential prerequisite to achieving a fully computer-based facility for availability calculations, but it also has value in its own right. It is a concise record of the systems design and of the predicted typical operation patterns of vessels. The discipline of producing information for it has benefit to designers and designs and even to operational staff. The dependency charts can be used directly to study the design for weaknesses which may lead to low availability and mission profiles can contribute a feeling for operational significance of the functions involved with a design weakness.

Even with the intrinsic value of the paper model as described above, the existence of an automatic data processing facility in the form of the already developed computer models vastly extends the facility for drawing consistent and comprehensive availability information. A description of these computer models follows.

The Computer Models

These models comprise a Model Update Program, a Steady-State Facility, a Sequential-State Facility, and a Real-Time Simulation.

The Model Update Program

This program is the basis of all of these modelling facilities. It enables the computer to accept information in punched card form, convert the logical relationships into Boolean algebra and assemble the whole ship into mathematical expressions and data stores. It can print out total chart information and Boolean algebra expressions. Charted design information and data can be changed without further chart work and the line printer output inspected. Chart checking by the computer is inbuilt to detect errors in logic, omissions, and so on.

Provision has been made for modelling even the largest and most complex warship foreseen. The capacity available in terms of maximum numbers of each modelling feature is given below with the figures in brackets being those actually used for the MCMV: Charts, 60 (24); SDLs, 2000 (480); major system functions, 480 (114); input/output functions, 320 (57).

Referring to Fig. 2 again, it can be seen that dependency chart information is entered into the computer files via two sets, A and B, of standard 80-column punched cards which represent the left- and right-hand sides of a chart respectively. The appropriate control card Set E (Fig. 3) is used via the Control Unit to select the programs for entering data and for the line printer to reproduce facsimiles of the chart or charts entered. Once the update sequence is complete, there is no need to use card Sets A and B again until the stored data needs revision.

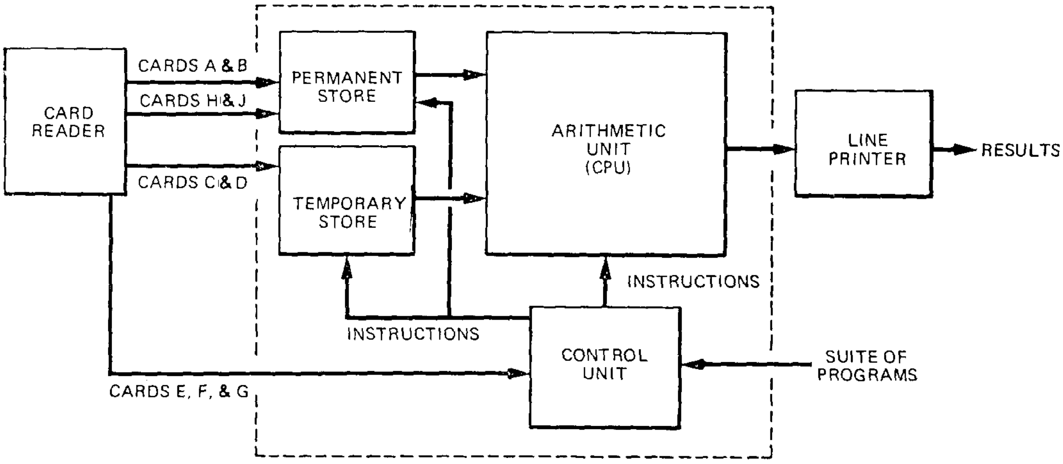

FIG. 3—THE 'COMPUTER MODEL'

Mission Availability Concepts

Before proceeding any further, it is useful to distinguish between two availability parameters, the first being conventional and the second being specially defined for present purposes. Conventional or steady-state availability is not a time dependent parameter; it relates to the situation obtaining after statistical equilibrium has been reached in the ratio of cumulative uptime to cumulative downtime. However, for mission availability this has to be qualified because all ships have a significant number of equipments with failure modes for which repairs cannot be made at sea. Once an equipment fails in such a mode at sea it is unavailable and remains so. Therefore, the availability of such failed equipments and their parent systems is mathematically zero, which is of no value as output data. This has been overcome by considering steady-state availability for only those failures which are repairable at sea. For those which are not, the reliability is calculated for the stated period at risk and is combined with the steady-state availability for repairable-at-sea failures. The resultant is called Instantaneous Mission Availability and naturally it will be lower than, or equal to, the steady-state value. It is a much more realistic and meaningful parameter than the steady-state one and a comparison of the two gives a good indication of the effects of not being able to repair specific failures at sea.

Steady State Facility

This facility or model derives its name from the steady-state nature of conventional availability data but, even so, reliability and instantaneous availability data have been included in the outputs. The facility merely provides the extra organization needed for the Model Update Program to be used for the efficient production and printing of selected results. In addition to calculating the steady-state and instantaneous availability and reliability of each SDL and major system function, the steady-state facility also calculates the availability levels and the probable number of repairs to each SDL. As an indication of the relative importance of SDLs, Dependency Coefficient Tables are compiled which show the dependence of major system functions, availability levels and the whole ship on each individual SDL. Another refinement is the so-called V Factor. This is a number printed out against each SDL which represents the sensitivity of the availability of that SDL to changes in its failure and repair data. Thus an SDL with a V factor higher than the norm is a candidate for reliability or maintainability improvement.

There are two possible sets of results for each characteristic, one derived from its own chart in isolation and another from the complete model. The former assumes that any functions required from other charts have availabilities of unity and the latter takes such inputs with availabilities as currently calculated. There is one further difference: isolated chart results have their times-at-risk all set at a nominal mission time whereas the complete model results are for adjusted times at risk. Thus the latter results are more useful in many ways than the former. Each SDL is put at risk in accordance with its time-at-risk code, i.e. either for calender time, mission time, running time, or even not at all, depending upon the characteristics of the equipment. All of the results obtainable are based on mean failure and repair data and there is only one set of results for each mission period stipulated.

When a run is required of the steady-state facility a card of Set F (FIG. 3), appropriate to the range and type of outputs desired, is used. This selects the required programs and the central processor will solve the equations using stored ship data, and output the results. Note that no mission information is needed in the temporary store for these sequences to occur.

The Sequential State Facility

This facility is a development of the previous one involving the use of mission information as depicted on the Mission Profile charts. The relevant equipment combinations are put at risk during each mission activity in the sequence envisaged for real operations. The print-outs available include: a reproduction of the appropriate mission profile chart; Boolean statements expressing the dependencies of each activity on major system functions; lists of SDLs involved and the probable number of repairs carried out by the ship at sea or with forward support unit (FSU) assistance; the availabilities of major system functions at mission start and end; and the ship availability at the start and finish of each activity further analysed into SDL availabilities.

The predicted availabilities obtained will depend upon the repair policy stipulated as part of the model input data. For example, during certain activities all repairs may be inhibited; during others some repairs will be carried out as failures occur but other repairs may be deferred. Some repairs can be carried out using onboard facilities; others may need the help of a FSU. Almost any repair policy that can be thought of can be entered.

The reader is referred to part 6/2 of Volume 3 of the *Ship Availability Modelling Handbook* for full details of the sequential-state outputs available.

The sequential state facility in common with its predecessor is a 'stochastic' model: that is, it is based on the probable behaviour of large populations of similar equipments or, in other words, mean failure and repair data. Therefore there is only one set of output probabilities for each mission profile chart. It follows that the facility cannot adapt to the real life options of going to a standby or repair activity should the main activity fail. It continues from activity to activity up to mission end and is not diverted by probable equipment failures.

Inspection of FIG. 2 shows that mission profile chart information is entered into the computer temporary store by means of card Sets C and D, which represent the left-hand and right-hand sides of the chart respectively. This data, unlike ship data, is freshly entered for each run. The appropriate control card Set G will result in the central processor carrying out the calculations appropriate to the mission and the presentation of the outputs required.

Cards, of Sets H and J, containing repair schedule data are entered into the permanent store only when mission control cards, of Set G, are selected, i.e. only when mission data is being entered into the temporary store for the first time.

The Real Time Simulation

This facility is the final model and differs from its two predecessors in not being based on a stochastic process but uses instead the random generation of failure and repair events. This is achieved by a Monte Carlo process based on the exponential or other selected distribution of events about mean values already entered on the dependency charts.

The facility is capable of simulating an actual ship mission consisting of a series of activities as depicted on a mission profile chart. As before, the relevant equipment combinations are put at risk for the appropriate period of each individual ship activity.

During the simulation, failures of equipments cause activities either to cease or to continue with alternative equipment. Facilities exist to continue the same activity with reduced capability, go on with the next activity, resort to a fallback activity, heave to for repair, or abort the mission. If repair is possible, the original activity can be resumed when the repair is complete. If an FSU is available, it can be called upon to assist, with its ability to do so being randomly generated to conform to its stock out probability. This is one example of the simulation taking into account repair restraints; it can also respond to limits on shipboard spares, repair time, and repair men. Due to the limited number of repair men, a queuing priority may have to be allocated.

It can be seen that the facility simulates and responds to individual equipment events. Therefore, every mission carried out in whole or in part against a particular attempted mission profile is unique. Several runs can be initiated to generate a population of results to permit study of the significance of individual random events.

The number of potentially useful outputs from a real-time simulation is very large and in practice the number actually presented in the computer print-out is severely restricted to avoid a surfeit of data and paper. Provision is made for any particular programmed output to be printed out on request.

The following list gives some idea of the scope of the outputs from the simulation, but should not be considered exhaustive:

(*a*) Proportion of successful missions.

(*b*) Number of mission activities not able to start.

(*c*) Number of activities successfully completed.

(*d*) Number of SDL failures during each activity.

(*e*) Number of SDL failures not repairable at sea during each activity.

(*f*) Number of repairs (i.e. without external support).

(*g*) Number of repairs carried out by the Forward Support Unit, etc.

The outputs can be presented as mean values or maximum and minimum values.

Part 6/3 of Volume 3 of the *Ship Availability Modelling Handbook* describes in more detail the real-time simulation outputs.

The simulation can be run simply by using the appropriate control card Set G, providing that ship data, and the appropriate mission and repair schedule information is already in store.

Information Requirements

Clearly, for the model to be constructed for a particular application, a great deal of information has to be gathered together. It embraces the ship design, its operating philosophy, its repair and maintenance policy, and its equipment failure and repair rates. The modelling team can quickly build up a sound knowledge of ship systems and information sources and, although gathering and verification of the information requires the assistance of various Ministry and Service personnel, the demands of this task should not be overestimated. Ship information and the expected mission activities should be a part of the design process and should appear in the ship design documentation. However, it may be extremely difficult to define typical missions for most warships and obtain wide agreement that they are a sound basis for availability judgements.

Even so, some sort of mission basis for these judgements should be achievable, one fall-back option being mini-missions made up of one or more mission activities.

Reliability and repair data are obtained from a variety of sources. These include: published data books such as DX 99 (DASWE), manufacturers, and information retrieval systems such as SYREL (UKAEA), and, for naval experience, SMA. The newer the ship or the equipment, however, the less relevant are the data from in-service ships.

Obtaining repair times is not as straightforward as failure rates. In addition to using available data retrieval systems, information is derived from discussions with designers, maintenance evaluation teams, and from inspections of mock-ups. Allowance is made for similar equipments with different accessibility or other environmental influences.

Having obtained the best data available, attempts are made to quantify the confidence that can be placed upon them. SDLs are broken down into their constituent SRLs and, perhaps, even down to module or component level. It is these lower levels that have failure and repair data assigned to them. The combining of these data from their several different equipment types enhances the confidence in the SDL values significantly, provided that the contribution of no single SRL, etc. is excessive.

The accuracy of basic and derived data should be viewed with an understanding of the non-deterministic nature and legitimate uses of probabilistic information. Firstly, high accuracies of basic or derived data may not be required in their own rights and, secondly, considerable variation of some basic data may have little effect on dependent systems availabilities. Two further factors help in achieving useful modelling results. At equipment level, if failure rates are low compared with repair rates, equipment availability is relatively insensitive to these rates. Error factors of 2 in the basic data can generally be considered insignificant in that the change in equipment availability is only a fraction of one per cent. This applies to most equipments but for others, where the failure rate is much higher, the amount of failure data available is also much higher and therefore accuracy is likely to be much improved.

Application of the Model Outputs

Availability models are powerful tools that provide a great deal of information of a management, engineering, operational, and logistic nature. This information, which is of a predictive nature, permits action to be taken before irreversible situations occur. Particular applications of such information, many of which are just suggestions, are listed below:

(*a*) Identification of system configuration (dependency) weaknesses.
(*b*) Identification of major system functions with low availability.
(*c*) Identification of equipments, or combinations thereof, which have low availability.
(*d*) Indication of where changes in repair policy have a significant influence on ship effectiveness.
(*e*) Identification of where improvements in reliability and repairability achieve the most significant results.
(*f*) Calculation of reliability targets given required ship and system availabilities.
(*g*) Identification of the equipment likely to make most demands on the repair facilities.
(*h*) Identification of the mission activities most likely to be threatened by low availability.
(*i*) Quantification of the probability of success for mission activities.

(*j*) Assessment of the achievement of NSR availability objectives and to aid future specifications.
(*k*) Assessment of deployment requirements to achieve successful missions in given scenarios.
(*l*) Provision of the necessary availability predictions to aid operational studies.
(*m*) Assessment of the skills required on board and, if applicable, at the FSU.
(*n*) Assessment of the time required in harbour between missions.
(*o*) Assistance in stocking the FSU, if applicable.
(*p*) Assessment of what, if any, support transport should be made available between ship and shore.

A majority of these uses are known to be pertinent to new ship construction, conversion, or major refit projects in respect of project management and engineering staff. It is thought that several will be of interest to Naval Operational Requirements Staff and authorities responsible for ship operation and support.

It will be appreciated that often there will not be a clearcut choice of facility to meet a specific application. As a rough guide, designers will be mainly interested in steady-state results, operational staff will find the sequential-state and simulation outputs of more interest, and support staff are most likely to find the information they require in the data from the simulation.

Procedure for Creating and Running Specific Models

The general computer model and such specific ship models that exist are in the custody of Ship Department, Section D122, who have set up a Computer Bureau Service and will advise on modelling and act as an intermediary between users and the model.

If a paper model does not exist and is to be developed, this can be done by MOD staff or by appropriate contractors and, particularly for dependency charts, by the Shipbuilder. Section D122 will supply blank dependency and mission profile charts, Ship Model Equipment List blanks, and coding sheets. They will supply a loan copy of the Handbook and advice on the modelling process. They will arrange for punched cards to be produced for draft charts, and for dependency and mission profile chart cards to be run through the appropriate programs to check for errors.

When an acceptable paper model exists (as for MCMV), D122 will arrange that the required results are provided as print-outs. To do this, they will arrange for the appropriate facilities to be activated by means of the appropriate control cards which they will either select or create to meet specific user instructions. Ship data and mission activity changes will be effected and different mission profiles will be run as customers request.

Experience to Date

The MCMV is the first ship to have been completely modelled this way and has benefitted from the facilities created—from the paper model through to the computer simulation, It is not proposed to discuss this in detail; it would require a long article in its own right to do so.

A dependency chart has been created for a seagoing characteristic of a future nuclear submarine. This has been entered into the computer and steady-state availability predictions produced for this characteristic. Two other characteristics are in process of compilation and a mission profile chart has been drafted. Another future nuclear submarine will probably be modelled in total. This submarine modelling has been done by Y-ARD, not the developers of the model, and the ease with which the work has been done with minimal help illustrates the relative simplicity of the task.

Future Work

As far as the development of the model is concerned, increasing its capability as a logistics tool has drawn the greatest favour from potential customers. This might require using the spare part rather than the SDL as the model building block. There is no plan to proceed this way as yet. Other development targets may well arise from additional customer wishes which evolve during use of the facilities already provided.

Conclusions

A ship availability model has been developed capable of modelling individual ship systems and the whole ship. It has been designed to deal with the largest foreseeable naval ship and can cope equally well with other complex engineering systems.

The model can produce the following: steady-state and instantaneous availabilities for specific mission durations based on system dependencies depicted on the availability dependency charts; instantaneous availabilities and repair information at the end of each activity of a mission profile depicted on a mission profile chart; and a considerable amount of data on availability, equipment and system failures, and repairs, etc. from a series of runs of a real-time simulation. This information could be of great value to management, engineering, operations, and support staffs.

Any ship can be put through the facility as it presently exists. To prepare for this involves the compilation of the availability dependency charts and mission profile charts and the collection of failure and repair data. The investment in these activities should be well justified by the potential benefits in procurement and ownership.

Acknowledgements

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