DISCRETE SIMULATION OF THE TIGERFISH CONVERSION PROGRAMME

BY

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ABSTRACT

This article describes the application of the Discrete Activity-oriented computer simulation method to the management of the logistic problems associated with the conversion of the Navy's Tigerfish (Mk.24 torpedo) population from a Mod 1 to a Mod 2 build standard within industry during the mid 1980s.

Simulation models were built of the manufacturing processes associated with the conversion of four selected electronic and one electro-mechanical unit. The model time-span was divided into three parts: start-up, steady state and run-down, and included statistically controlled learning curves, failure-rates, scrap-rates and resource allocation. Model logic and control parameters were tuned periodically to reflect real-world performance and to take into account unanticipated perturbations such as shortages and strikes.

Model output was an error curve formed between prediction and target. This provided the project manager with a tool to aid decision making under conditions of uncertainty by allowing him to ask 'what if' questions.

Introduction

The MOD decided in the early 1980s to invest in a radical overhaul of the Tigerfish weapon system. To this end they appointed a prime contractor, Marconi Underwater Systems Ltd (MUSL), with the remit to upgrade the platform-fitted equipment and the torpedo itself with the aim of assuring weapon performance and effective whole-system integration.

A major element of this overall task was the need to modify torpedo hardware. The modification was of such a nature that it had to be done within industry and it affected the complete war stock. As a consequence it was necessary to guarantee that the war stock did not fall below a certain minimum level.

To achieve this objective the MOD agreed to deliver torpedoes to MUSL at a certain rate; MUSL in turn agreed to introduce the modification, test and return assembled torpedoes to an appointed MOD RNAD to a predefined programme.

As an aid to achieving the above objectives, MUSL, with MOD support, decided to construct a suite of discrete computer simulation models of the logistic/conversion system associated with the implementation of the above task, with the aim of providing the Project Manager with a tool which would aid decision-making under conditions of uncertainty. This article describes the successes and failures encountered in undertaking the modelling task.

Scope of Task

When constructing a model of a real-world system such as that to be described here, it is essential to establish the boundaries of the study, so as to constrain the size of the model within reasonable limits; similarly it is necessary to limit the detail of the model to a level which satisfies the resolution required.

Investigation of previous problems, soon resulted in a short-list of units which were expected to present the most problems. These were the:

(*a*) Homing Subsystem;
(*b*) Azimuth Unit;
(*c*) Fuze & Electronic Unit;
(*d*) Depth Unit;
(*e*) Tail Unit.

These are predominantly electronic equipments with the exception of the Tail Unit which is electro-mechanical. Thus the model suite was limited to five units.

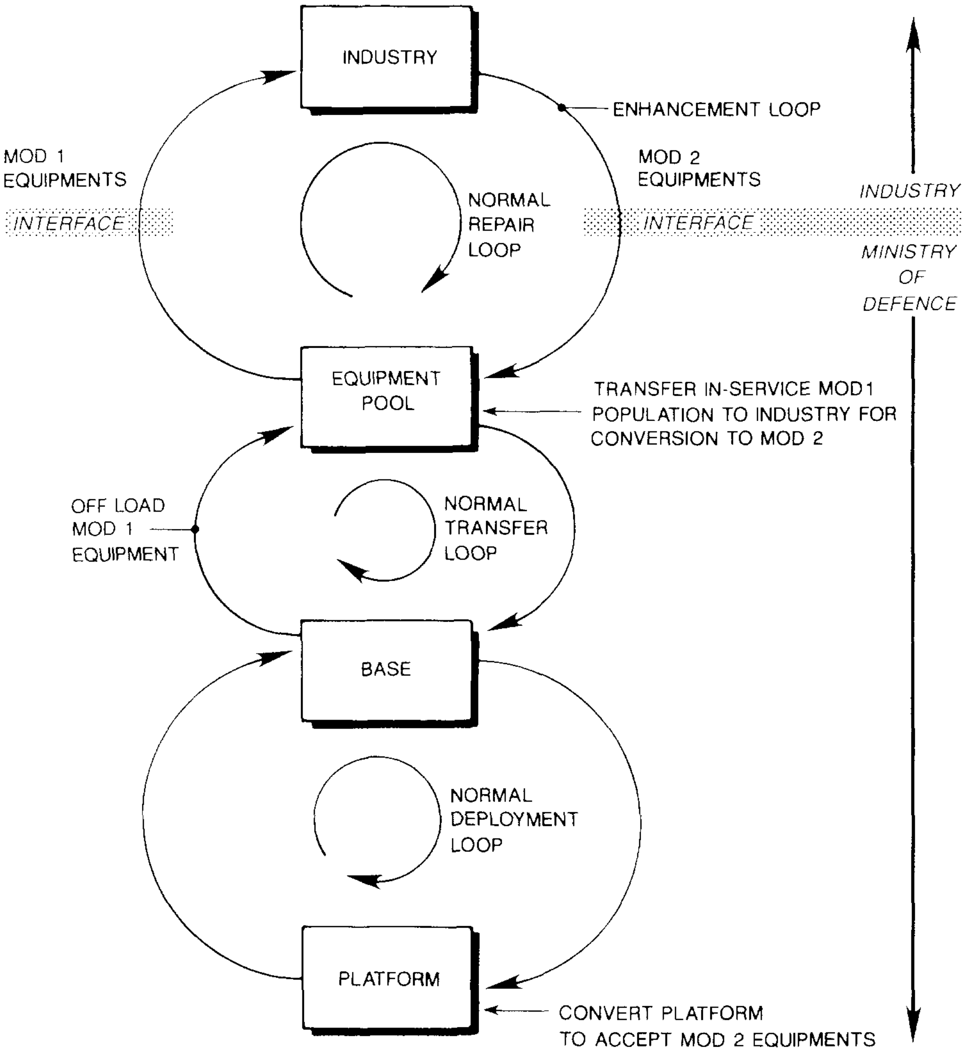

FIG. 1—OVERALL MOD.1/MOD.2 TORPEDO CONVERSION SCHEME

The basic high-level structure, from an MOD point of view, of the logistic flow is shown in FIG. 1. In essence the total population of in-service warshot and practice torpedoes had to be converted from Mod 1 to Mod 2 build standard by recycling them individually through an industrial work process. The Contractor had no formal visibility of any activity beyond the interface shown. Consequently his view-point was constrained to the top box in FIG. 1.

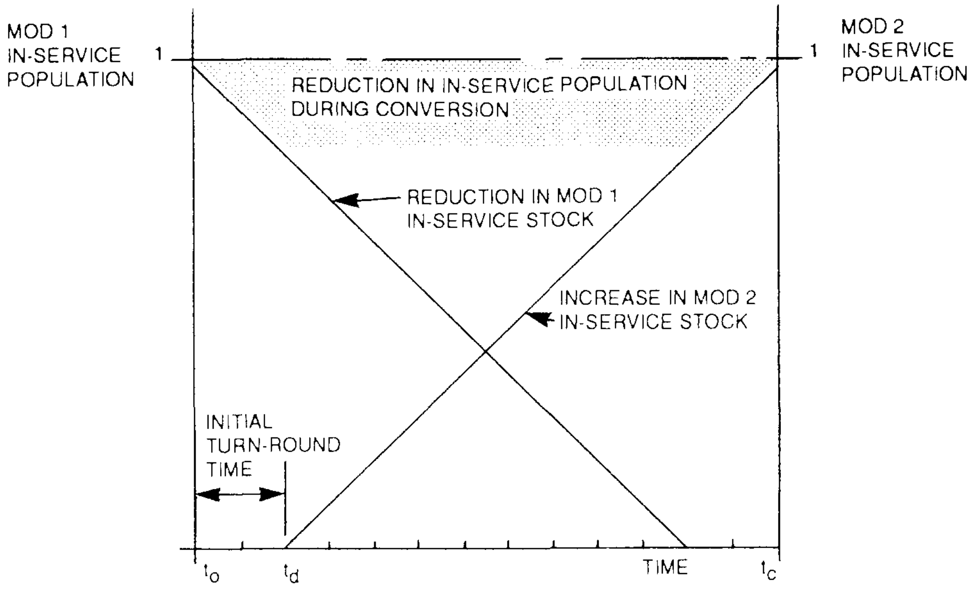

FIG. 2—SIMPLIFIED SKETCH OF THE CHANGE IN MOD.1/MOD.2 STOCKHOLDING DURING THE CONVERSION PROCESS (NOT TO SCALE)

t_o: start time
t_d: delay time
t_c: completion time

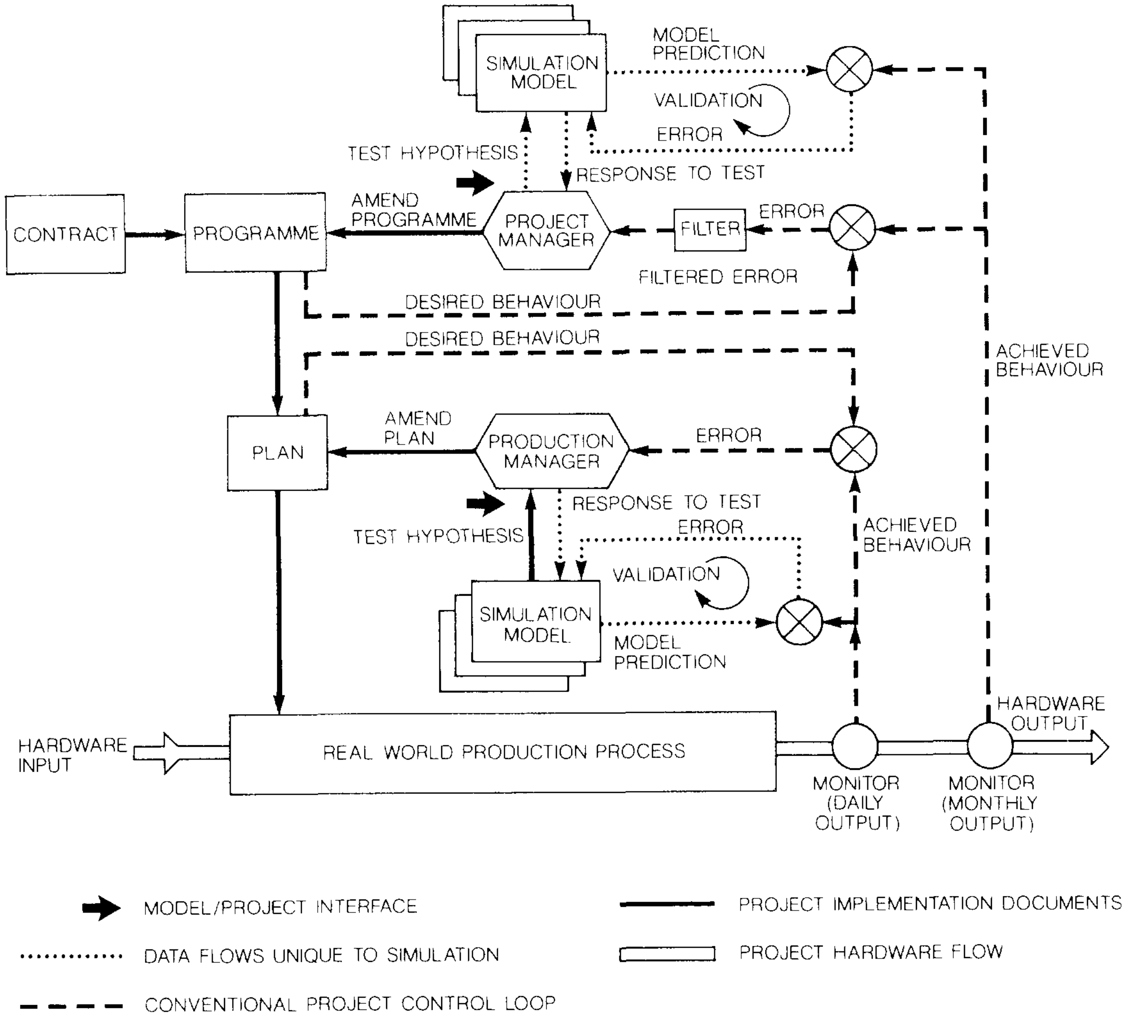

FIG. 3—THE APPLICATION OF SIMULATION MODELLING TO THE PROJECT MANAGEMENT TASK

The global task to be accomplished, again from an MOD standpoint, is illustrated in FIG. 2. The Contractor's interest focussed upon the conversion programme start time (t_0), the delay before return to customer (t_d), the conversion turn-round time (t_d—t_0) and the conversion programme completion time (t_c).

The conversion programme start and completion dates marked the delivery of the first Mod 1 torpedo to the contractor and the subsequent return of the last Mod 2 torpedo. The conversion programme itself was driven by an agreed Mod 1 batch delivery sequence, with the turn-round time being split into three phases: start-up, steady state and run-down. This aspect of the task was seen to be the most critical and so warranted the most attention. Consequently, the major focus of the model was on the production process.

Modelling as an Aid to Project Management

The major objective in constructing the model suite was to provide the Project Manager with a tool which would aid decision-making during the active phase of a project by allowing him to extrapolate from a known position into the future. To achieve this objective it was necessary to construct a base-line model using the best information available, then to refine and update the model as real-world data became available. The extrapolation function can then be seen as a moving window, with a view of the future which becomes more hazy with time.

FIG 3 presents this concept from a control system stand-point. In fact the scheme shown contains two distinct blocks, both utilizing a model suite—that of the Project Manager, and that of the Production Manager, the difference being in their control loop response-time.

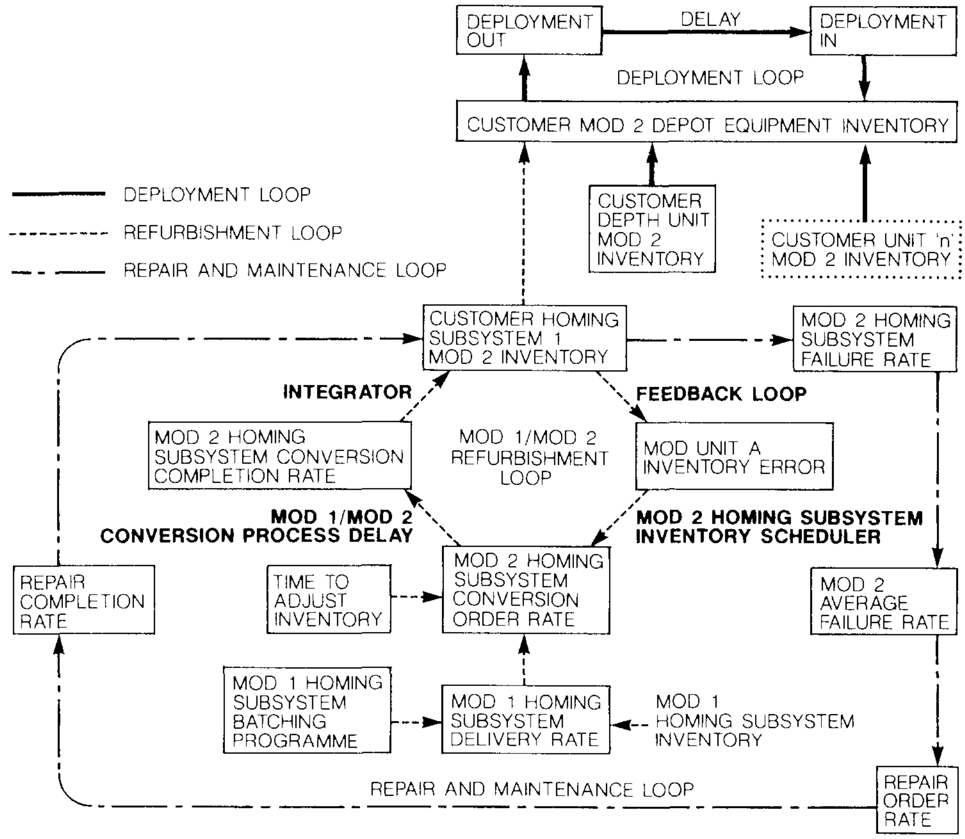

FIG. 4—LEVEL 1: ANALYSIS OF THE MOD.2 TORPEDO INVENTORY CONTROL SCHEME

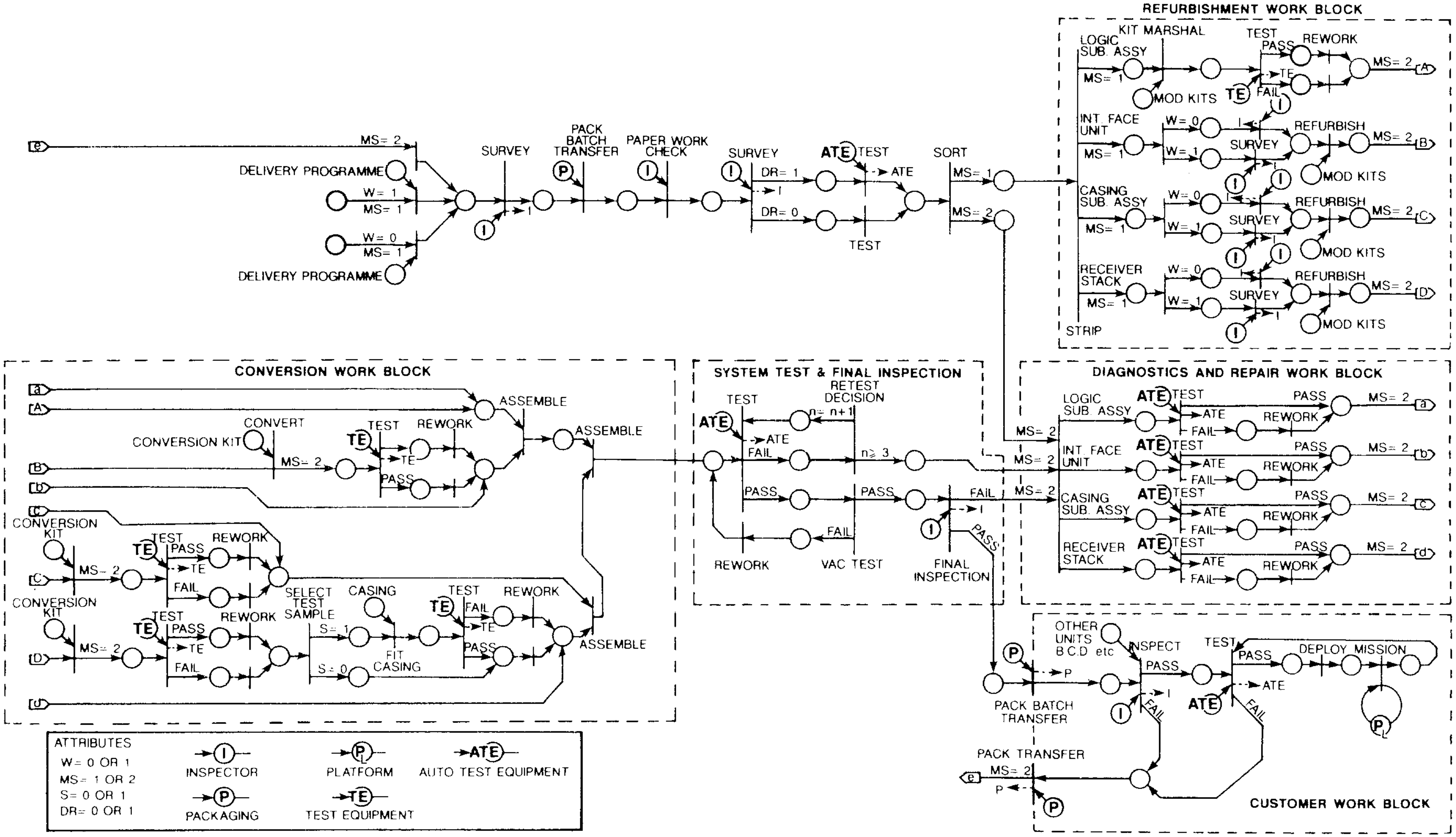

FIG. 5—LEVEL 2: PETRI NET REPRESENTATION OF HOMING SUBSYSTEM MOD.1/MOD.2 CONVERSION SCHEME AND THE SUBSEQUENT REPAIR & MAINTENANCE LOOP

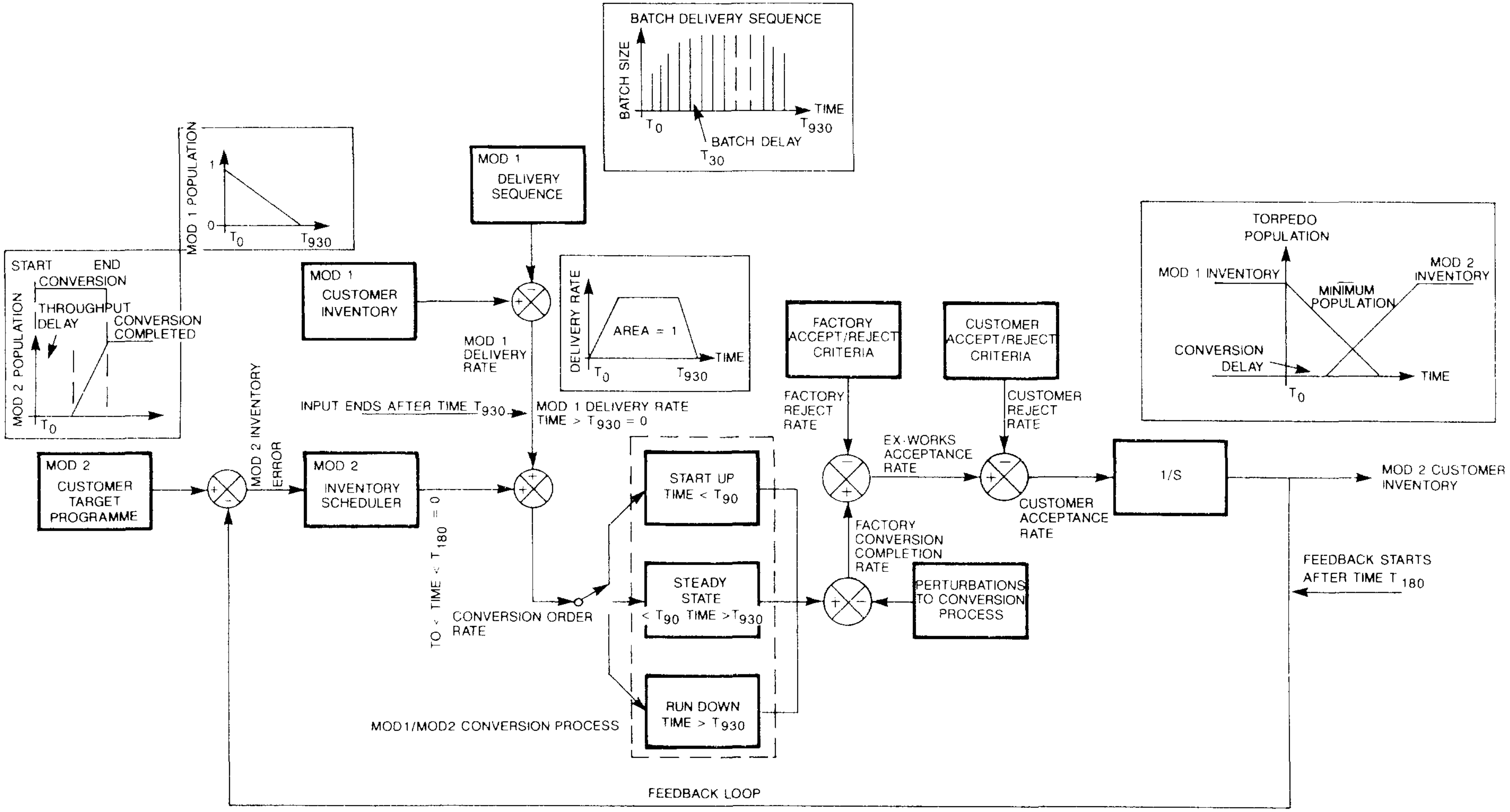

Fig. 6—Dynamic aspects of the Mod.1/Mod.2 conversion scheme. The system operates in Open Loop mode between times T_0 and T_{180}; Closed Loop mode starts when the first Mod.2 unit completes conversion. The system operates without input after time T_{930} when last Mod.1 batch of units is injected

System Analysis of the Homing S/S Conversion Scheme

Level 1

The base-line Homing Subsystem model was constructed on the basis of information gained by interviewing knowledgable production staff. The Level 1 analysis is shown in FIG. 4. The core refurbishment loop was described in more detail (Level 2) using the Petri net method shown in FIG. 5.

Level 2

The model described in FIG. 5 describes the logic of the scheme and is essentially passive in nature. A simulation model requires dynamic data. FIG. 6 provides this, it includes:

(*a*) model driving functions—the batch delivery sequence (spanning Project Time T_0 through to T_{930} days);

(*b*) Project Start-up Phase—Project Time $<T_{90}$;

(*c*) Project Steady-State Phase—Project Time $>T_{90}$, $<T_{930}$;

(*d*) Project Run-down Phase—Project Time $>T_{930}$;

(*e*) Project Turn-round time = 180 days, hence the system runs open-loop between T_0 and T_{180}, when first Mod 2 unit completes conversion, thereafter Mod 2 units can occur in the repair loop.

The factory and customer reject rates affect the throughput-rate. Perturbations to the conversion process covers all unplanned events such as strikes, shortage of resources, etc.

Level 3

The logic and dynamic information contained in FIGS 5 and 6 are combined in FIG. 7 to form a (Level 3) diagram which describes the conversion process in terms of a combination/sequence of timed Activities linked by Queues, the network being driven by a batch delivery sequence. In effect, units step through the sequence in time with a master clock over a period of 1080 Time Units (TU).

The network diverges into four channels (Receiver-Stack, Logic Sub-Unit, Interface Unit and Casing & Fixing) to reflect strip-down, and these subsequently converge to reflect re-build. The efficiency of re-build depends upon the throughput rate of the four channels staying in balance.

Activities cannot start unless a specified resource is available e.g. test equipment, inspectors, refurbishment kits, etc. The availability of resources can be controlled upon a statistical basis depending upon the best data available.

The network logic contains feedback loops which emulate re-work due to test failure. Test failures occur on a random basis with the failure rate specified being based on previous experience.

Activity times can be either fixed or statistical depending upon the best production data available.

Learning curves were employed for both throughput-rates and failure-rates. These were based upon the best advice available.

FIG. 8 is a comparison between model prediction and real-world achievement 77% of the way through the project. The effect of perturbations on real-world achievement is clearly illustrated. The model at this point in time is at issue 8, which reflects the degree of iterative tuning required to make the model track real-world production. The down-turn in production visible beyond T_{870} is due to the residue of the Mod 1 population in conversion at that point causing production difficulties.

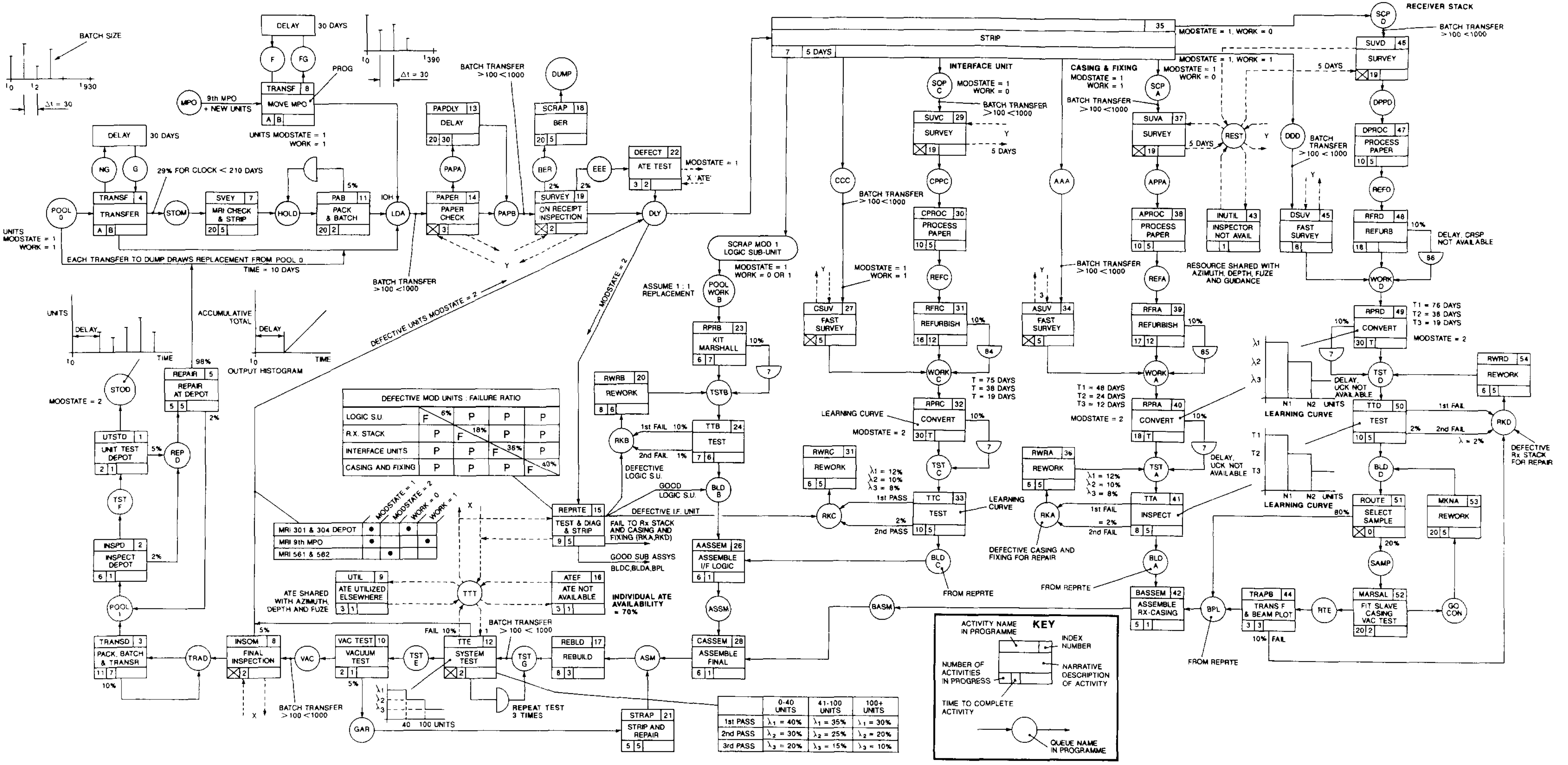

FIG. 7—LEVEL 3: ACTIVITY/QUEUE REPRESENTATION OF THE HOMING SUBSYSTEM CONVERSION SEQUENCE

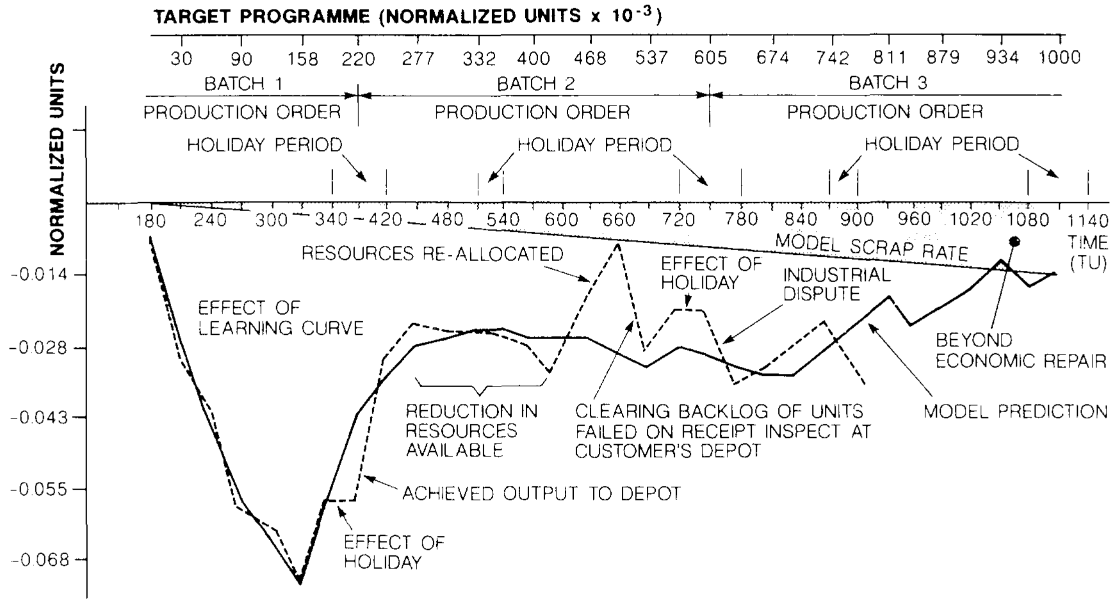

FIG. 8—PREDICTED AND ACHIEVED OUTPUT FROM THE HOMING SUBSYSTEM CONVERSION PROCESS TO TIME T_{870}

FIG. 9 is an example of an Activity Block. It shows the System Test Activity (A.TTE). This activity transfers units from Queue TSTG (Q.TSTG) to Q.TSTE, if any one Automatic Test Equipment (ATE) out of a set of three is available in Q.TTT. A three-step throughput learning curve has been employed to reflect start-up problems.

An ATE can be withdrawn from Q.TTT by either A.UTIL, A.ATEF or another use (emulating ATE failure or alternative use). The decision to transfer an ATE to A.UTIL, or to A.ATEF, from Q.TTT is random, and the time the ATE stays in A.UTIL, or A.ATEF, is dependent upon a previously selected statistical function.

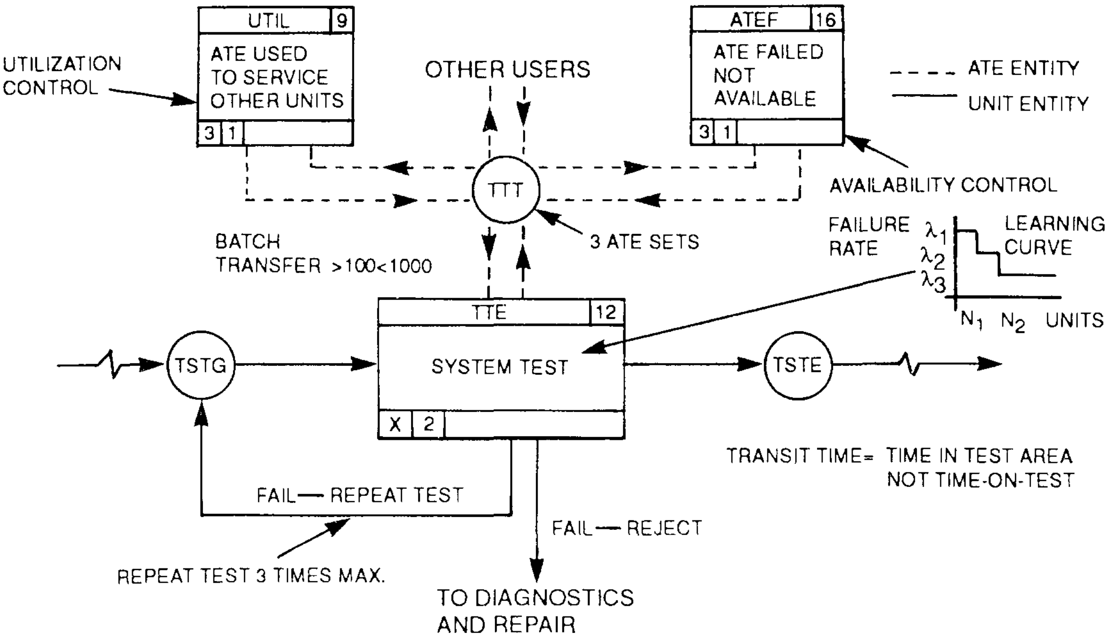

FIG. 9—ACTIVITY/QUEUE REPRESENTATION OF AN ATE TEST STATION
ATE: Automatic Test Equipment
UTIL, ATEF, TTE: Activity labels
TSTG, TTT, TSTE: Queue labels

The test failure/diagnostic strategy adopted requires three successive test failures before a unit is sentenced as defective. In addition, a variable failure rate has been adopted to reflect start-up problems. This combination of failure rate learning-curve and diagnostic strategy is shown in FIG. 9.

Discrete Simulation

Real-world systems can be classified in various ways depending upon their characteristics and the interpretation of the modeller. For example Continuous-time (or change) models can simulate Partial or Ordinary Differential Equations, and also Discrete-event and Process-interactive systems, whilst Discrete-time models can be used to model Activity-scanning systems, and systems described by Difference Equations and Markov Chains. The system described in this article was classified as an Activity-scanning System, because:

(*a*) individual items in the problem moved through the networks described by activities and their associated queues;

(*b*) The events simulated occured unevenly in time.

Some commercially available Discrete simulation software packages are:

Event Scheduling: GASP II&IV, SIMSCRIPT 1.5, II & II.5, SLAM II, SIMAN,
Activity Scanning: AS, CSL, ECSL, ESP, SIMON,
Process-interactive: GPSS/360, V & /H, Q-GERT, SIMSCRIPT II.5, SLAM II, SIMAN, SIMULA.

In general, the UK has favoured the Activity-scanning methods, whereas the US has favoured the Event- and Process-interactive methods.

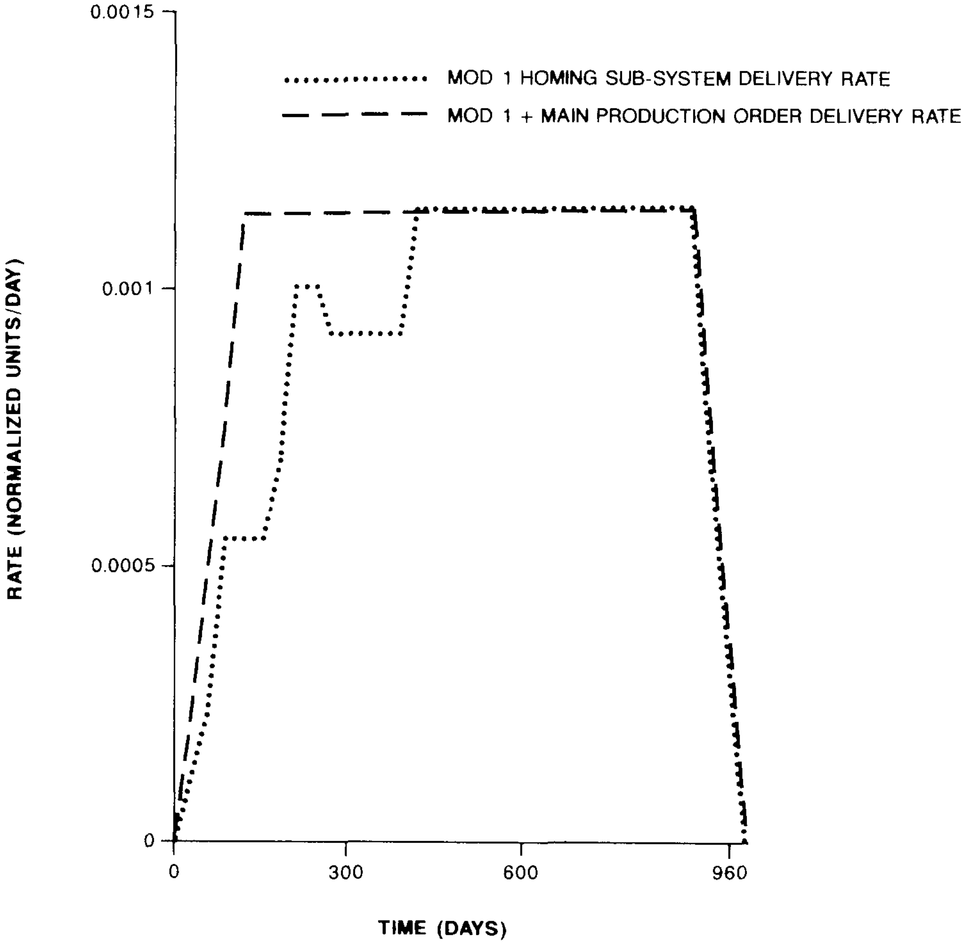

FIG. 10—HOMING SUBSYSTEM DELIVERY RATE DATA

Implementation

The model described in Fig. 6 was implemented using a dedicated Activity-Orientated, Discrete Simulation Language known as ECSL (Extended Computer Simulation Language). This is a high level, 3-phase language based upon Fortran, developed in the UK from 1960 onwards and extended in the late 1970s by Birmingham University.

The model was run on an Apricot PC; run-time for the Homing subsystem model exercised over 1080 cycles plus printer output time was about three hours.

Project and Model Input and Output Data

The stimulus to the model is shown in Fig. 10. The input-rate is normalized relative to the total Homing Subsystem population. The Mod 1 delivery-rate is the rate at which units were withdrawn from the MOD inventory and delivery to industry. The MPO (Main Production Order) units were new Mod1 units which had never been delivered and which were being modified to Mod 2 build standard before delivery to the MOD. Deliveries were ramped between T_0 and T_{420} to allow for start-up delays. The surge between T_{210} and T_{240} was designed to support a trials programme. Roll-off at the end of the delivery-sequence was rapid.

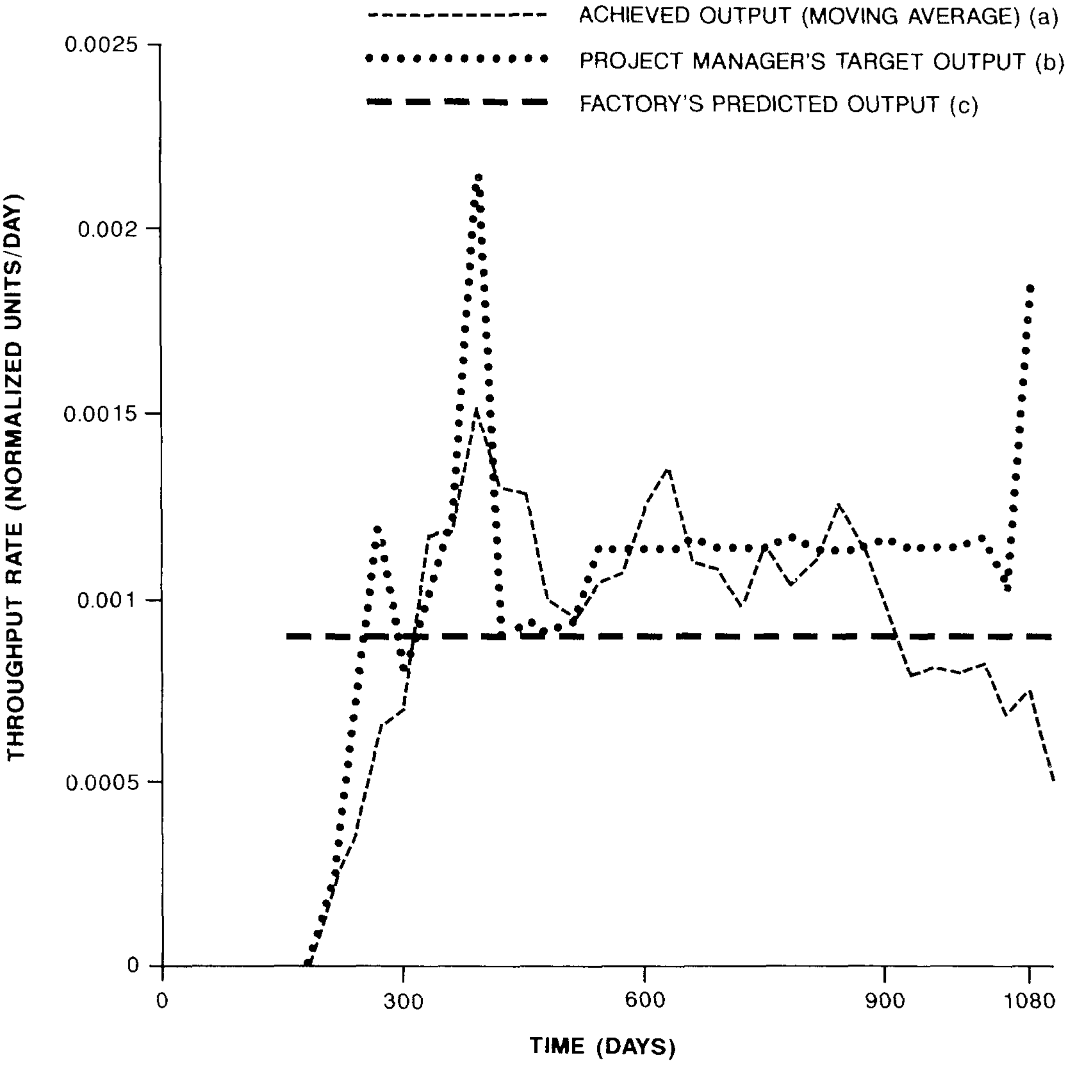

Fig. 11—Mod.2 Homing Subsystem achieved acceptance rate

FIG. 11 shows three graphs which represent:

(*a*) the actual achieved output shown as a 3-monthly moving average;

(*b*) The Project Manager's required output based on his contractual commitment;

(*c*) the factory's predicted output shown as a constant rate.

FIG. 12 shows error between achievement and target.

Start up. Both (*a*) and (*b*) of FIG. 11 show the effect of learning curves at project start-up throughput rates. The impact of this effect on the error curve (FIG. 12) is apparent between T_{180} and T_{390}, when the maximum error for this phase occured. From FIG. 11 it can be seen that actual throughput rate never recovered to achieve the target (peak) throughput rate required at T_{390}.

Steady State. During the Steady State phase the error oscillated about a mean value, at about −2% of target between T_{420} and T_{900}. The throughput rate shows a similar pattern and indicates that the factory did not have the capacity allocated to recover.

Run down. FIG. 11 shows a continuous reduction in throughput rate from T_{840} to T_{1080} with a consequential divergence between target and achievement. As would be expected the error curve matches this roll-off in achievement.

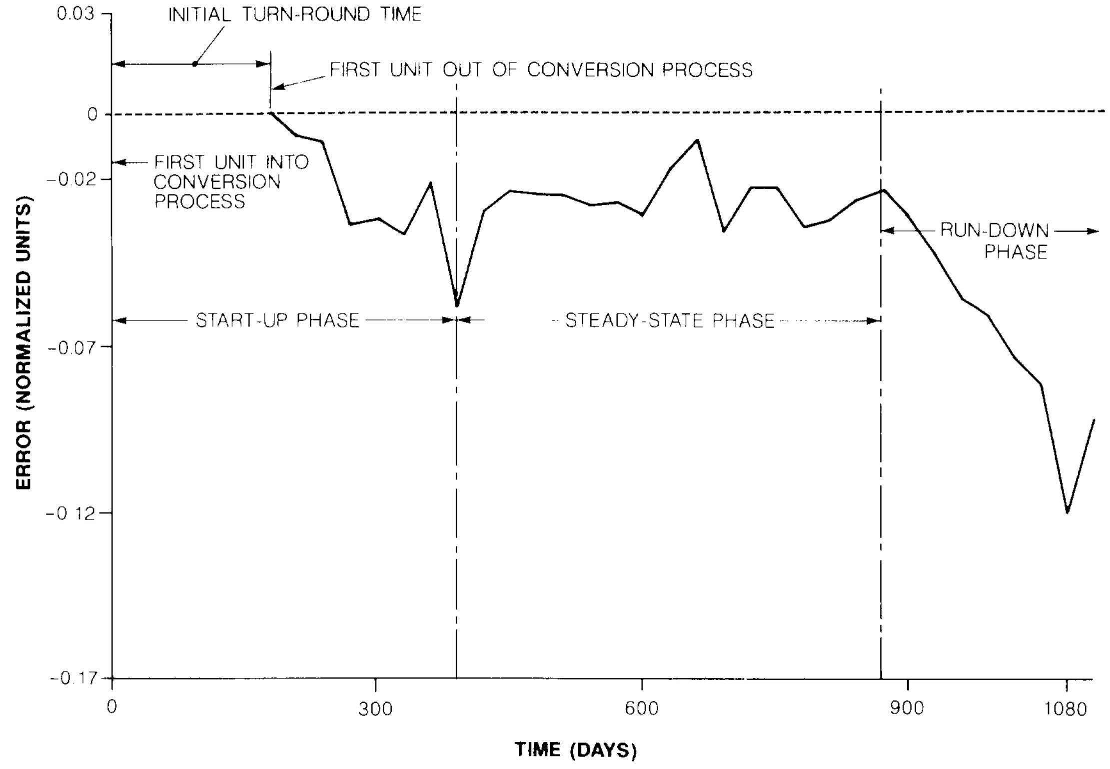

FIG. 12—MOD.2 HOMING SUBSYSTEM ACHIEVED INVENTORY ERROR

FIG 13 provides an overview of the conversion programme performance from the MOD's point of view, between T_0 and T_{1080}. A constant lag of about 30 days is observable between target and achievement over the period T_{270} and T_{930}; after that roll-off occurs until T_{1080} when data ends.

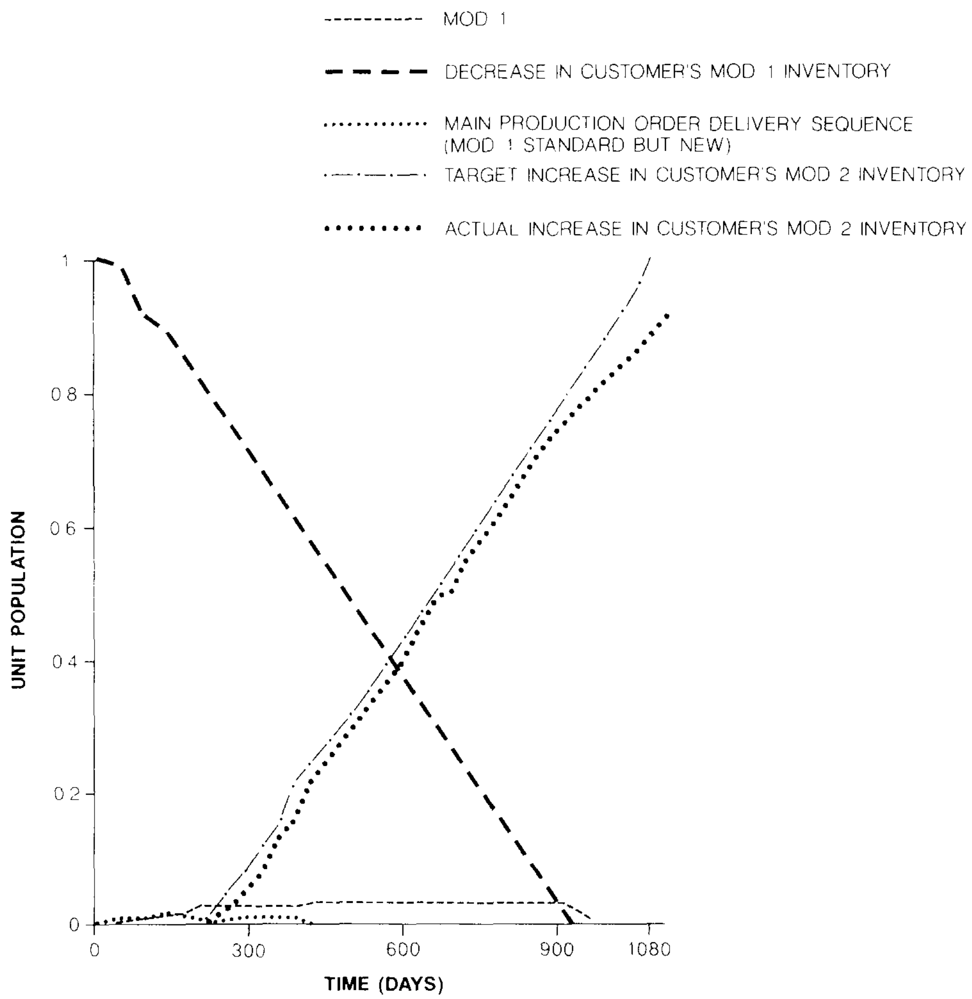

FIG. 13—HOMING SUBSYSTEM CONVERSION DATA (REAL)

Post-Project Review

The body of data captured during the construction and validation of a computer simulation model of a manufacturing process such as is described in this paper would be of value during a post-project audit whose aim would be to:

(*a*) identify for posterity the cause of problems encountered during the course of the project;

(*b*) justify factors which could affect the final profit margin, such as cost over-runs and/or late completion;

(*c*) ensure that the scope and content of any future model is suitable for the task in hand.

The ability of a company to learn from experience enables it to become far more competitive when competing for future fixed-price contracts. They are thus able to prepare quotations based upon fact and prediction rather than intuition. Post-project analysis should increase management's confidence in the model, hence the contingency element of the estimate could be reduced, and as a consequence, the bid price could be lower.

Model credibility, in advance of project start-up, rests mainly on the way in which it caters for a parameter whose character can change, either by intent or accident, during the project timescales. Predictable changes occur to production throughput rates. Initial estimates of these variables rely mainly upon demonstrated 'track record', but post-project credibility rests upon the robustness of the model, i.e. the flexibility with which unforseen perturbations, such as strikes, are handled. This model characteristic is better gauged with hindsight.

The experience gained during the performance of this task indicates that whilst the logical structure of a work process can be determined with confidence beforehand, its long-term dynamic characteristics cannot. Instead, any model must be continuously tuned in response to real-world achievement, an objective whose attainment is very much dependent upon access to good production data.

Postscript

The work described took place over the period 1984 to 1987. At this time discrete simulation software packages were making the transition from running on large machines to running on PCs. Current (1992) packages offer more sophisticated model-building, data analysis and output functions, and, given that PCs are also much more powerful, then discrete simulation modelling should be a tool in every project manager's tool-box.

Acknowledgment

The work reported here formed the basis of a PhD thesis[1] submitted to the University of Wales, Cardiff. Important publications on the subject are listed below as references[2,3,4,5].

The author wishes to acknowledge the assistance and support of MOD/DGUW(N) and MUSL Waterlooville, and the guidance and advice given by the academic staff of the Dynamic Analysis Group at UWIST.

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