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SIMMAT: An Aircraft Materials Remanufacturing System Simulation Model

Part I: Background and Concept

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SIMMAT: An Aircraft Materials Remanufacturing System Simulation Model

Part I: Background and Concept

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Remanufacturing consists of repair or refurbishment of worn parts and products. Systems involved with remanufacturing differ from more traditional manufacturing operations in terms of material and work content characteristics. Parts are subject to variable recovery rates and lead times, while service requirements are unknown in advance and processing times are stochastic. This paper describes a remanufacturing system for aircraft engine servicing, and discusses the use of simulation to support with its planning and scheduling. Literature is reviewed on planning and scheduling for complex and dynamic industrial systems, particularly job shops. Features and characteristics are discussed of an actual aircraft materials remanufacturing system located in Christchurch, New Zealand. Finally, the conceptual design is introduced of a prototype data-driven simulation model proposed for decision support with this system.

Keywords: remanufacturing; planning; dynamic; stochastic; data-driven; and simulation.

1. Background

Remanufacturing is a process involving the repair or refurbishment of worn parts. Systems involved with remanufacturing differ from more traditional manufacturing operations in terms of material and work content characteristics. Typical assemblies, for example aircraft engines, are disassembled and worn parts removed for repair or scrap. Parts are subject to variable recovery rates and lead times, while service requirements are unknown in advance and processing times stochastic. Remanufacturing often involves specialist operations, such as machining or surface treatment, carried out in finite capacity job shop environments.

With job shop environments, parts for different low-volume orders frequently arrive at irregular intervals and follow different sequences through resource centres [20]. These resource centres are grouped by function to accommodate the varying customer-specialised requirements, as well as variations in demand for products and service. Job shops as such are dynamic systems that are difficult to plan or schedule. When linked to remanufacturing the problems encountered can be acute given that work volumes and processing requirements are not known in advance. Furthermore, the mix of jobs arriving and the condition of each part instance will also be unknown.

Planning and control strategies for firms involved with remanufacturing tend to be complicated. Inventory costs associated with remanufacturing are also high with buffer stocks of serviceable parts required so that assemblies can be serviced and reassembled by a required date given the uncertainty. It has been estimated that remanufacturing operations with good scheduling and control systems can achieve inventory cost savings of over 40 per cent compared to less efficient competitors [16].

Remanufacturing systems would in general benefit from the availability of quantitative or logical representations, of structure and operation, that could be used to:

- Evaluate scenarios involving alternative strategies and practices; or
- Evaluate schedules and make forecasts about a system's future state.

A number of methodologies are available from the operations research and systems modelling disciplines to develop support tools. Performance and capacity in many industrial situations is for instance often studied using networks of queueing models. This approach was taken with regard to strategic planning for an American Airlines' landing gear repair flow shop [21]. However remanufacturing systems, particularly those operating as job shop environments, do not consist of networks ie, the service routings followed by parts are neither standardised nor predetermined. Credible representations of any remanufacturing system also need to incorporate considerable detail ie, gross simplifications would result in a model with little utility as a tool to support with planning and scheduling (operational planning). Discrete-event simulation is realistically the only way to develop a model that has many variables and interacting entities, nonlinear entity and variable relationships, and also contains random variables. The process approach to discrete-event simulation was frequently encountered, with general-purpose languages sometimes used to augment developed code [2, 5, 6, 7, 8, 12, 14, 15, 17]. General-purpose and object-oriented simulation languages were often used with more advanced operational planning systems [1, 18, 19].

There has been little work involving performance analysis and capacity planning for complex dynamic job shops, particularly where remanufacturing is concerned. Effort has, however, been aimed at developing systems, rules, or strategies for the planning and control of job shops. One common theme has been applying order review and release, as well as prioritisation rules, to control release to and movement around the shop floor [7, 8, 12, 15, 17, 20]. Alternative strategies were compared using simulation studies, and conclusions drawn, as to which methodology or scheme is appropriate in the given circumstances. The reviewed simulation studies generally involved simplistic job shops rather than systems of job shops, the model used by Guide and Srivastava being an exception [7]. Typically, the arrival of work was treated as an intermittent rather than planned function, and effected using stochastic probability distributions. Findings made with some studies differed from those of other studies, highlighting the need for care when generalising findings from hypothetical simulation experiments. Some of the more sophisticated systems discussed in literature used artificial intelligence and heuristics to assist with scheduling and short term rescheduling, handling production disturbances, and the assignment of staff. Examples relate to manufacturing job shops, flexible manufacturing systems, as well as ports [1, 9, 19].

However, the reviewed articles indicated simulation based schedulers or decision support tools to be decisive tools for operational planning. Control systems and production databases were typically in place for these examples, and the preordained nature of operations meant processing requirements could be ascertained in advance. One approach, direct database simulation, involved the use of relational database data as a simulation model [10]. However all these approaches require databases to handle and record the details on which specifications of current and future processing requirements can be determined. The common lack of such information for manufacturing systems was noted to be a problem [10, 14, 18].

Operational planning for remanufacturing job shop environments using simulation has not been reported in the existing literature. With such environments the induction of assemblies may be planned, but the jobs to be received off each assembly, their times of arrival and processing requirements are unknown. However, it should be possible to make forecasts regarding workload and processing requirements. Pratt and Whitney reportedly apply probabilities determined from historic information to anticipated cases when planning aspects of aircraft engine remanufacturing [13]. Use of forecasting models to analyse historical data and predict future material flows were also reported with a simulation based container port decision support system [19].

This two-part paper sets out the development of a prototype data-driven simulation model for an aircraft materials remanufacturing plant in New Zealand. The model was intended as a tool to assist with strategic planning for the remanufacturing system. Its basis as a model driven by exogenous inputs should also facilitate operational planning.

2. A aircraft materials remanufacturing system

Air New Zealand Engineering Services operate an aircraft materials remanufacturing system on their base in Christchurch, New Zealand. This system, known as the Materials Repair Group, is part of the Airmotive Group responsible for aircraft engine servicing and overhaul. It is primarily involved with the repair and refurbishment of parts off Pratt and Whitney JT8D and Rolls Royce Dart engines. As well it conducts refurbishment, repair and custom manufacturing for other airline service groups and some external customers. The Repair Group is expected to process a large volume and wide variety of parts, cope with varying workloads, and manage competing demands for resources. Varying engine conditions and customer requirements mean the volume and type of jobs handled will fluctuate considerably.

Schedules of assembly induction and finish dates are specified for each service group. These groups, particularly service groups on the base, are continually inducting assemblies such as aircraft or engines. Once inducted, any disassembly is carried out and servicing requirements ascertained. There will be contracted dates for each assembly's release, with timeframes for the completion of processing developed as standardised appraisals or estimates specified through experience. These timeframes are divided into interim periods that correspond to particular stages of processing such as engine disassembly.

After disassembly or analogous handling, jobs that require repair or refurbishment, together with requests for custom manufacturing, are forwarded to the Repair Group. These jobs might be single items, batch lots, or 'stands' of engine parts for cleaning or testing. They arrive in the repair system with documented details of the repairs to be made and services carried out. All received work is released immediately to the shop floor to follow specified routings for service.

Routings are usually unique to a job although influenced by a part's nature, and the history of itself and its parent assembly. They can be simple and involve a visit to single section where a single resource is used or service carried out. Alternatively a succession of sections may be visited with multiple operations carried out in each. A routing can also include visits to external service vendors or other groups on the base. The times for individual processing operations to be carried out are effectively stochastic with the nature of operations being so variable. Transit delays often occur when work moves internally between sections, as well as moving to and from processing that is external to the Repair Group.

Target dates for the completion of processing within the Repair Group will be specified as part of each job's documentation, although these may be renegotiated if unreasonable. A routing may also be modified part way through its course if defects or a need for further processing are identified.

The Repair Group consists of several self-contained job shops partitioned into sections. Sections are organised so similar tasks are performed and related items of equipment grouped together. It operates on a two-shift basis, five days per week, with overtime and additional shifts worked when required. Around 75 staff of all designations work in the Repair Group spread between two shifts. There are foremen and leadhands who manage the shops and supervise operations together with processing staff who perform operations.

Five shops and two support groups constitute the Repair Group. One support group inputs processing details to a production database, as well as providing 'release to service' certification for serviced parts, and technical support for corrective actions when repairs are defective. The shops divide into sections with each shop having equipment resources appropriate to its role. A Process and Cleaning shop is responsible for painting, cleaning and chemical treatments, as well as compressive stress treatments. Magnetic particle and dye penetrant inspections are carried out in the Non-Destructive Testing Shop. There is a Machine Shop and Reconditioning Bay that provides assembly, disassembly and fitting services, and also possesses varied machining, milling and grinding capabilities. Metallic plating and electro-plating surface treatment processes are carried out in a Plating Shop to give protection against wear or corrosion, enable physical processing, and rebuild worn surfaces. Welding and heat treatment, together with plasma rebuilding of worn surfaces, is carried out in a Welding Shop. Some specialist processing such as x-ray testing, is conducted by other service groups on the Christchurch Base. Processing can also be outsourced to external service vendors when operational or capacity constraints exist. A second support group exists to manage outsourcing. Figure 1 is a depiction of operational layout for the Repair Group.

When resources are unavailable, queues usually form for requested equipment or operators. It is difficult to forecast the delays that will occur or identify those shops that will be affected.

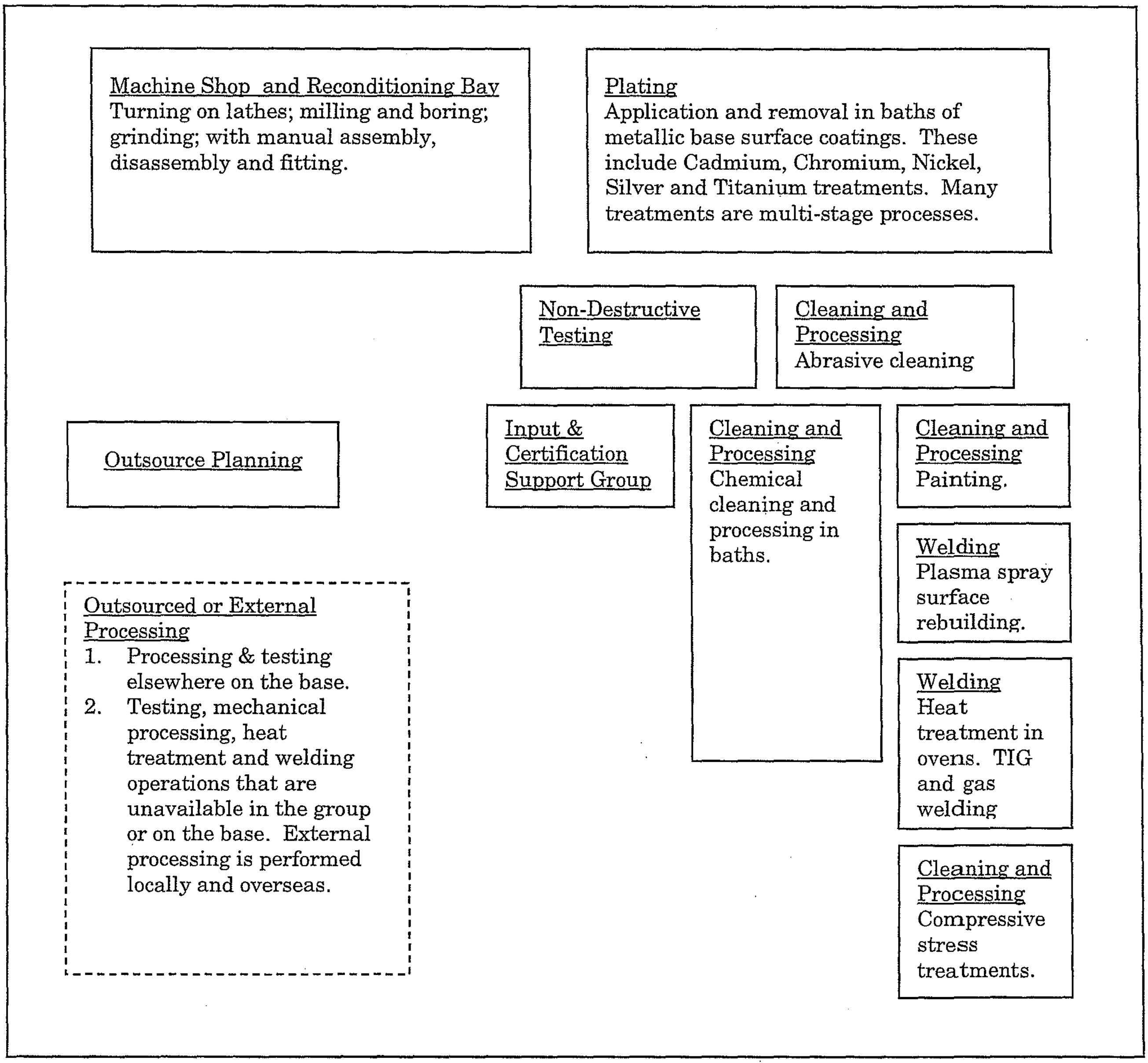

Figure 1: Layout overview for the Materials Repair Group

A control, tracking and production database system is used to track each job's position along its routing, prioritise work queueing for resources, and apportion overhead costs of maintenance. Estimates of the labour content of processing, or man-hours, to be undertaken in each section are recorded into the tracking system. These are estimated using experience, or historic records of equivalent jobs. As the processing staff complete each operation the actual processing man-hours are also recorded. Bar codes are affixed to job documentation so that when processing is complete, a job can be moved to the next area of work and its location recorded. Timeframes for the completion of processing in each routed section are partitioned into interim periods, with each stage demarcated by an interim target date. These are determined by partitioning the overall timeframe, with measures of shop or section workload at each stage used for weightings.

Critical-ratio rules are applied so waiting jobs receive increased priority the closer they are to their target date, taking into account the time estimated to remain for the completion of processing. The ratios are of the form

$$r_s = \frac{h_s}{h_r}, \tag{1}$$

where h_s is the manhours estimated to remain until some target date, and h_r is the estimated processing man-hours still to be carried out. A critical-ratio will reduce in value as a target date is approached relative to the man-hours of work still to be processed. Ratios become negative if a target date has passed. Delays still occur with this system however, especially when a processing resource becomes a bottleneck or too much work is received at once.

Target dates can be tightened where a job requires increased priority to be completed on time. Target dates can also be extended out where a target will not be met, but substitute parts are available which reduces the urgency. Processing timeframe extensions will also be made if defects or a need for further processing are discovered.

3. A remanufacturing system simulation model

A prototype simulation model of the Materials Repair Group, for operational planning purposes, was conceived as a data-driven discrete event simulation operating over simulated time. Its logical engine resembled the interacting factors that constitute the system with entities created and conditioned through exogenous data inputs. Over a simulated timeframe it reads, on a daily basis, information regarding staffing levels and the work to be received. Details such as probability distribution parameters or quantities that cannot otherwise be estimated are also specified externally. Figure 2 gives a conceptual overview.

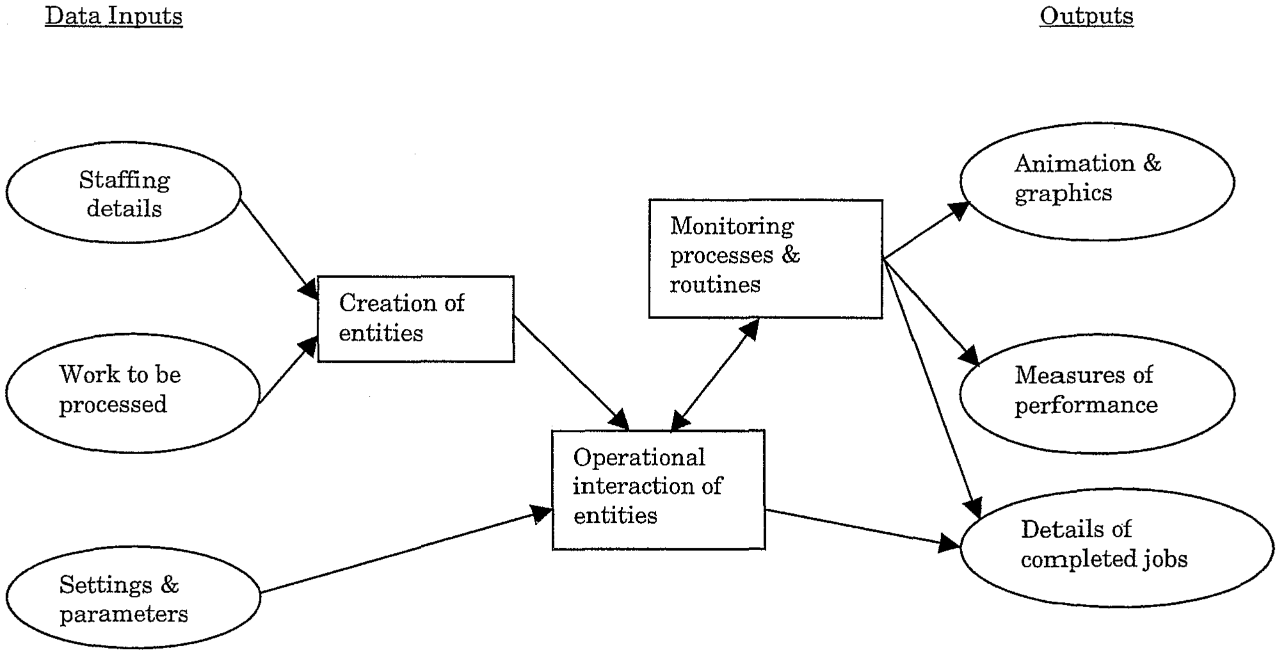

Figure 2: Schematic diagram of the conceptual model. Throughout execution the model's state records to file. Inputs and settings are supplied from computer files, while measures of delay and performance are also recorded externally.

As a program the model is constructed from statements of structured logic to represent a non-networked system of equipment resources. There are entities that mimic staff and the jobs processed by these staff. Other structures coded into the model effect the shops and sections of the Material's Repair Group. It is set to run over a simulated period of time with information read from files to trigger the creation of:

- Staff entities that operate each day in a shop or section; and
- Job entities that follow specified routings for service and repair around the shops and sections.

Through processes and control logic similar to that of the actual system, staff entities simulate the processing of jobs, while the same jobs compete for staff and resources, and queueing mechanisms are effected. The external determination of staff entities together with job characteristics and volumes has analogies to reality. It also allows complex and dynamic behaviours to be developed through the interactions of relatively simple entities. Sample structure diagrams depicting logic followed by staff and job entities are presented in figures 3 and 4.

Some delays, such as when jobs are outsourced or sent to other service groups, could not be represented using stochastic values. The length of such delays is as much a function of vendor or service group as a characteristic of the job or processing resources. Accordingly such delay durations are specified exogenously along with details such as each job's service routing.

Another issue is the representation of specialist processing integral to, but not part of the Material's Repair Group ie, processing conducting by specialist service groups. These groups' workloads include processing that does not originate from the Repair Group. Queueing mechanisms could not describe the delays associated with these specialist service groups given a lack of information on their overall workload compositions. So within the model delays associated with specialist processing are represented using temporary interruptions to arrest a job's progress. Such interruptions are generated using probability distributions appropriate to each specialist service group.

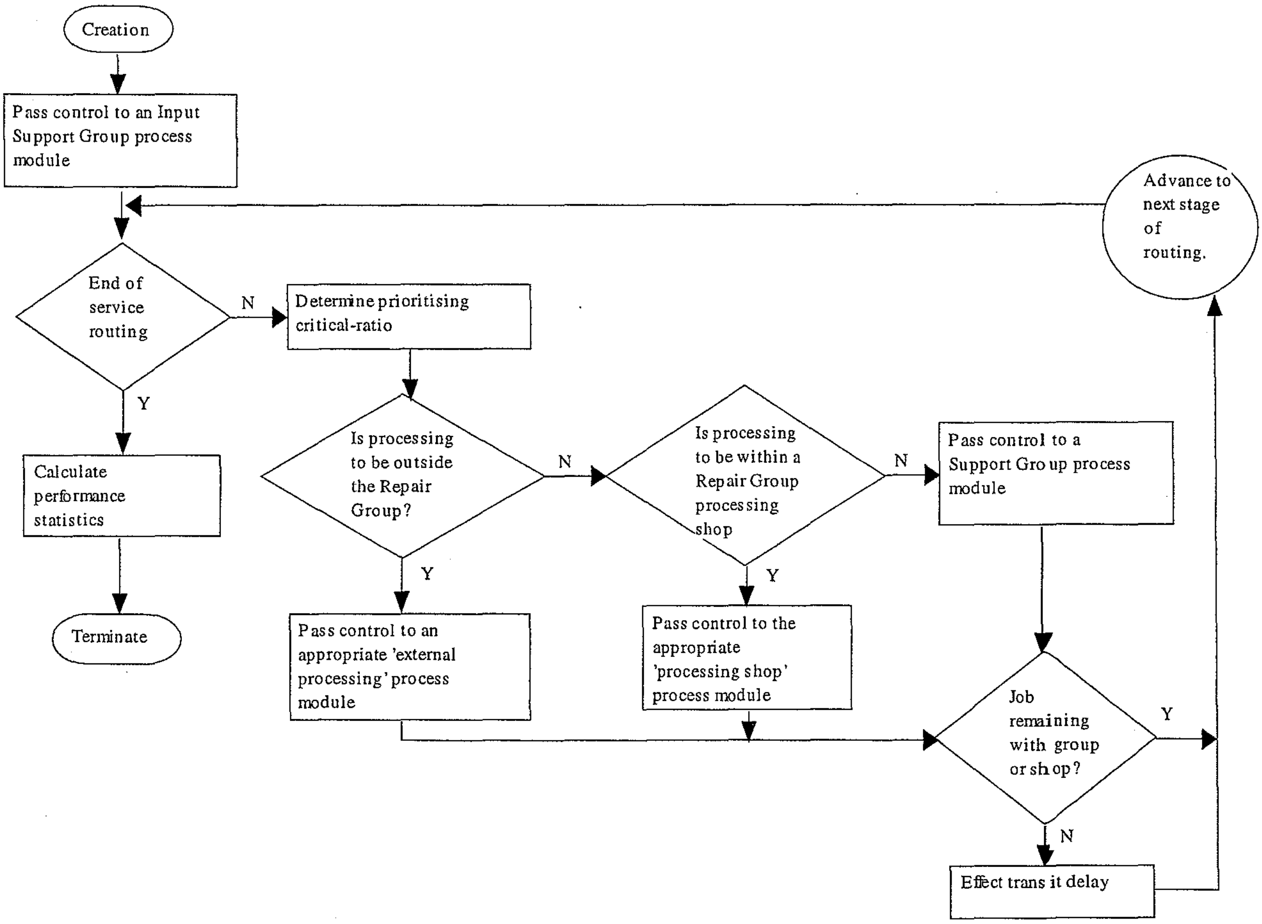

Figure 3: Sequential logic followed by job process entities. Processing and handling is effected through processes that represent the shops and support groups. Shop and support group process modules are responsible for the equipment resource queues that are in turn monitored by staff entity processes.

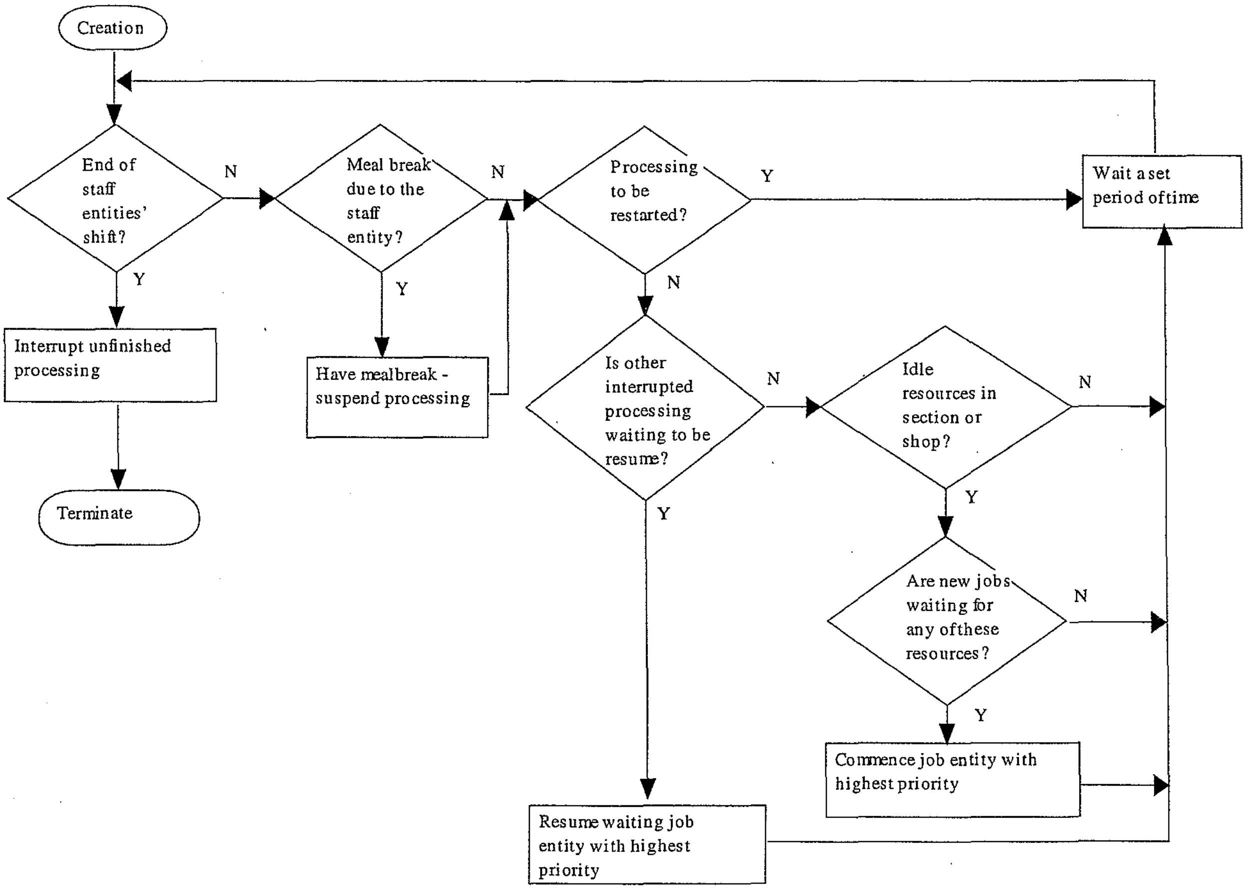

Figure 4: Logic systematically followed by a processing staff entity. Staff entities associate themselves with a job and stay associated until released by the job. The process entities themselves have finite durations equivalent to a single shift. New staff process entities are created at the onset of each new shift.

Throughout execution the model's state is expected to record to file, with appropriate performance measures also being displayed using graphical animation. Various processes supported by routines are required to operate in the background monitoring performance or driving the animated displays or export of performance measures.

4. Discussion and reflection on the provision of data

Rationale was presented for a remanufacturing system simulation model that could be used for operational planning. The conceptual model is a data-driven system of interacting entities operating in a non-networked framework, useful for strategic planning, as well as the operational planning, control and management of processing. Its data-driven design should allow a dynamic and complex industrial system to be mimicked, where the data fairly reflects processing requirements and conditions over a period of time.

The outlined model differs somewhat from traditional discrete event simulations presented in texts like that by Law and Kelton [11]. Such models are generally intended for strategic planning and design with events generated internally. However it is akin to 'trace-driven' simulations where static models are driven by historical data.

Historical information can be used to calibrate a model and also to investigate how past scenarios might have been better managed. This requires production databases with the capability to monitor a system's condition and workload, archive data, and process collected details into profiles of a system's state from some historical point to the present. With the discussed remanufacturing system a modern enterprise resource planning (ERP) system, based on SAP AG's R/3® software, is being installed with this potential.

The ERP system will possess a database of staff availability and shift duration referencing the historic, current and planned assignment of labour, along with other system settings. Conceptually similar databases have been referred to with other simulation based Decision Support Systems [14, 19]. Processing requirements and other details of received work will also be recorded by the system.

Recording extended arrays of information should also enable profiles to be built of work to be received, by substituting historical records for the details of anticipated work. It is proposed to substitute, albeit with modification, historical data on work received off particular assembles, or cases, for the details of anticipated work. Where historic and anticipated cases are closely matched it should be possible to:

- Indicate if and where bottleneck delays are possible; and
- Show how work to be received will likely affect the work currently on hand.

One approach to forcasting the details and requirements of work to be received would be the application of probability referenced to each scheduled or anticipated assembly's age and operational history. The application of probability to scheduling aircraft engine inspection and rebuild has been reported by Merrle [13]. Another approach would be case-based reasoning [22]. Records stored in a production database that are referenced to a parent assembly would form cases of previously received work. Using case-based reasoning the characteristics of scheduled assemblies would be estimated by retrieving a case similar to an anticipated case, and adapting the retrieved case to the new situation. With either approach it would be possible to provide a data-driven simulation with profiles of anticipate work and conditions for the purposes of operational planning.

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