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A SIMULATION OF SYNCHRONOUS MANUFACTURING AT A NAVAL AVIATION DEPOT

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ABSTRACT

The planning, scheduling and control of repair/remanufacture (REMAN) operations has received considerable attention among practitioners over the past few years, but little attention from academia. The premise of this research is that significant improvements can be made in the planning, scheduling and controlling of REMAN operations by the application of the principles of synchronous manufacturing developed from the Theory of Constraints (TOC).

Normally scheduling requires standards relating to part routings and processing times. These standards are not available in remanufacturing due to the stochastic nature of the amount of work and the routings required to rebuild a unit. TOC avoids this problem of standards by (1) identifying the constraint and (2) the use of Buffers and Buffer Management. This approach makes the use of approximations to standards acceptable.

The implementation of synchronous manufacturing involves the modification of performance measures and adoption of drum-buffer-rope (DBR) as a planning, scheduling and control system. Synchronous manufacturing does not require the expense of purchasing or developing in-house MRP software, nor does it require the high degree of data accuracy at all points. A model showing if significant improvement could be achieved by a REMAN firm adopting the principles of synchronous manufacturing would be of benefit to practitioners and academics.

1 RELEVANT LITERATURE

The APICS Dictionary (Seventh Edition, 1992) defines remanufacturing as:
"An industrial process in which worn-out products are restored to like-new condition. In contrast, a repaired or rebuilt product normally retains its identity, and only those parts that have failed or are badly worn are replaced or serviced." However, for many processes the distinction between remanufacture and repair may be blurred. The literature related to REMAN operations rarely makes a distinction between the two terms. The key problem area for remanufacturing that most authors identify is that of imperfect information or the uncertainty that results from imperfect information (Boyer, 1991; Klussman, 1990; Carney, 1988). The concept of imperfect information can be readily understood by all manufacturing organizations; e.g., incomplete knowledge of the volume of orders for a time period. In repair operations this problem becomes more pronounced since repair operations must also cope with imperfect knowledge about the amount of labor and material a product may require for it to be fit for use again. Since the amount of rework required on any item is a function of the conditions the part was subjected to, any number of scenarios regarding the reparable item is possible. An incoming item must be inspected before any decision may be made whether the part is to be reworked, used as-is, or scrapped. The rework decision may also introduce uncertainty. The number of operations required and the time required at each repair operation may be unique for each part since each unit may have varying amounts of wear. This uncertainty in the required number of repair operations and time required at each operation makes materials and capacity planning in remanufacture industries more difficult than in traditional manufacturing industries.

2 RESEARCH METHODOLOGY

The purpose of this research is to determine what amount of improvement is possible by operating the depot under the principles of synchronous manufacturing. To estimate what level of improvement is possible the research will use a simulation model to compare values of the system performance measures under present operating policies with the values of the system performance measures under synchronous manufacturing. The present operating policies are the Navy and DoD policies, performance measures and rules, and regulations governing depot operations. The procedures advocated by synchronous manufacturing include the use of drum-buffer-rope as a planning, scheduling and control mechanism (buffer management), and a different performance measurement system. Specific research questions to be addressed are:

(1) Number of quarters completion to schedule not 100%

H_0: There is no significant difference in the number of quarters completion to schedule not met under the two methods.

H_1: Number of quarters schedule not met under present system is not equal to the number of quarters schedule not met under synchronous manufacturing.

(2) Work-in-process levels

H_0: There is no significant difference between WIP levels resulting from different methods.

H_1: WIP levels under present system is not equal to WIP levels under synchronous manufacturing.

(3) Idle Time

H_0: There is no significant difference between material idle times under both methods.

H_1: Material idle time under present system is not equal to material idle time under synchronous manufacturing.

(4) Number of units completed within allowable turn-around-time (TAT)

H_0: There is no significant difference between the number of units completed within the allowable TAT under both methods.

H_1: Number of units completed within TAT under present system is not equal to the number of units completed within TAT under synchronous manufacturing.

(5) Frequency of expediting

H_0: There is no significant difference between the number of units requiring expediting under both methods.

H_1: Number of parts requiring expediting under present system is not equal to the number of parts requiring expediting under synchronous manufacturing.

(6) Time in repair system

H_0: There is no significant difference in the time units spend in the repair system under both methods.

H_1: Time in repair system under present system is not equal to time in repair system under synchronous manufacturing.

(7) Multiplier for assembly buffer sizes

H_0: There is no significant difference in system performance measures resulting from different buffer sizes.

H_1: There is a significant difference in system performance measures resulting from different buffer sizes.

The model will include two basic types of variables: exogenous and endogenous. In this model, the exogenous variables can be most easily explained as Navy and DoD policies governing the operations of a depot. These policies include, negotiated turn-around-time (TAT), procurement policies and lead times for individual items, material availability, utilization of facilities, performance measures for workers, rate of induction, transportation availability, and number of units required by NAVAIR for that quarter (work load). In the long run, all these variables, with the exception of the work load, are controllable and may be changed if there is sufficient reason. The endogenous variables include work-in-process levels, actual turn-around-time, percent completion to schedule, material idle time, and frequency of expediting.

The system performance measures are normally selected from endogenous system variables (Hoover and Perry, 1989). Accordingly, the system performance measures used in this study will be actual TAT, percent completion to schedule, WIP levels, and material idle times. The primary performance measure for the Navy is meeting the quarterly requirements for specific amounts of specific models (performance to schedule) within the negotiated TAT.

3 PROBLEM FORMULATION

The problem under study is from the engine components division at the Alameda Naval Aviation Depot. The component, a Reduction Gearbox (RGB) is required on all propeller-driven Naval aircraft. In the past Alameda has experienced difficulties meeting quarterly requirements and turn-around times for RGBs. The RGB consists of over 800 parts, but only a small fraction of these parts account for over ninety-eight percent of all late shipments. Pareto analysis conducted on entries into the final assembly logbook listing parts requiring expediting, identified only nine parts as consistently late to the final assembly area.

4 DATA COLLECTION

The arrival rate of RGBs to the depot is based on the needs of the fleet. Prior to each quarter a list is sent to the depot identifying the quarterly requirements. The planner for the engine components attempts to induct the required number of RGBs on a level schedule. Twenty-one quarters of historical demand records were provided by the depot and a discrete probability distribution was derived from the records for use in the simulation model.

The depot provided the routings (MDRs) for each of the nine components to be modeled. These routings included flow times calculated by the operations analysis division, descriptions of the required operations, and the shop responsible for the work. The actual processing times for parts and frequency of the operation being performed on a particular part was not standard information maintained by the depot. The Industrial Engineering work standards had not been updated to reflect changes in work content and were calculated for the average work time, with no indication of the variability of the time required for the task. In order to get an estimate of the variability inherent in an operation, workers doing the actual operations were interviewed to find out the minimum time, most likely time and the maximum time required for an operation. Frequency of operations required were estimated by auditing forty records of finished RGBs and recording the frequency of each operation.

Information on resource availability was gathered by determining the number of machines normally used for a particular task, the number of operators or workers normally available and the number of shifts per day. Transportation times and the frequency of transportation to and from the engine division to other areas of the depot were collected, as was information on lead time required for procurement and availability of replacement parts. The performance measurement instruments for hourly workers, shop foremen, division foremen and division superintendents were provided by the Navy.

5 MODEL DEVELOPMENT

The simulation model for the depot was developed using SLAM II and FORTRAN coded user-written inserts. There are nine types of parts flowing through a total of twenty-nine shops. Master routings for each part was provided by the depot, as were actual processing and set-up times, and capacity available for each shop.

6 MODEL VALIDATION

In the model of the depot the simulation output data for delays in final assembly should not be significantly different from the data gathered from the final assembly logbook. Pareto analysis of the frequency of parts requiring expediting shows that the simulation model provides a good approximation to the actual frequency of parts requiring expediting at the depot. Law and Kelton (1991) warn that the comparison of output from simulations and real-world systems is difficult since both systems are normally non-stationary and autocorrelated, making the use of classical statistical tests impossible.

7 ANALYSIS OF OUTPUT

The depot model is a discrete-event, nonterminating system. To determine where the transient phase ends on the depot model, idle times were recorded for the part with the highest variability in processing times and repair operations and then plotted against the observation number. By using the part with the largest amount of variability will allow convergence of the other parts' idle times and will provide a good estimation of the transient phase. It was estimated that the transient phase ends at time 3120 hours (or 2 quarters) into the simulation and data collection can begin at this point.

Another problem in analyzing simulation output concerns the issue of number of runs required to achieve a specified level of precision. Kleijnen (1987) recommends the use of the following formula to determine the number of runs required:

$$n = \left(\frac{t_{n_0-1}^{\alpha/2}}{c} \right)^2 s_0^2 \qquad (1)$$

Where:
n - number of simulation runs required (sample size)
c - half-width of confidence interval
s_0^2 - sample variance for n_0 observations
$t_{n0-1}^{\alpha/2}$ - t-statistic with n_0-1 degrees of freedom n_0 - number of pilot runs of simulation
If $n > n_0$, then take $n - n_0$ additional observations. The mean will be updated, but the sample variance will remained fixed at s_0^2. Kleijnen (1987) suggests that c be estimated by c = .20(x). However, Law and Kelton (1991) advise that other factors, such as the nature of the experiment and the cost of replications should be considered when making decisions about the desired half-width of the confidence interval. The number of runs required was calculated for

all of the system performance measures and the largest economically reasonable value of n was used for collecting observations.

The method of paired t-test comparisons was used to calculate the confidence intervals used to test the hypotheses in this research. The method of paired t-tests comparison is favored over two sample t-tests in interpreting simulation output among a number of systems (Kleijnen, 1987, Law & Kelton, 1991). Paired t-tests are favored for output analysis since the variance is minimized, resulting in a smaller confidence intervals (Kleijnen, 1987, Law & Kelton, 1991, Bratley, Fox & Schrage, 1987). Common random number seeds in conjunction with synchronization of the random number seeds were used so as to allow paired t-tests.

8 SYNCHRONOUS MANUFACTURING MODEL

Umble and Srikanth (1990) define synchronous manufacturing as:
"...an all-encompassing manufacturing management philosophy that includes a consistent set of principles, procedures, and techniques where every action is evaluated in terms of the common goal of the organization.".

In order to implement synchronous manufacturing at any organization three major elements are necessary: (1) Define the common goal of the organization in terms that can be understood by all, (2) Develop the causal relationships between individual actions and the common goal, and (3) Manage the actions taken so as to achieve the greatest benefit (Umble & Srikanth, 1990).

Synchronous manufacturing is unique in that it explicitly recognizes the fundamental problems that plague remanufacturing/repair industries. In all manufacturing, dependent events (event B cannot start until event A is completed) and interaction of these dependent events occur (Umble & Srikanth, 1990). In addition, synchronous manufacturing recognizes the realities of stochastic environments (Umble & Srikanth, 1990). Repair of any product is subject to randomness on many levels. Part mixes are probabilistic because what part needs repair is not known until the product is inducted, disassembled and inspected. Routings are dependent on the nature of the repair required. The processing required at each step of the assigned routing is also a time random variable. The length of time required at any given operation may be a function of the degree of wear of the part and the operating conditions to which the part has been subjected. These stochastic elements combine to make capacity planning for a REMAN operation more difficult than in a traditional manufacturing environment.

The simulation model of the depot environment has a number of stochastic elements. The set-up times and processing times are drawn from a beta distribution (approximated from user-collected data), the probability of a particular routing being required is drawn from a user-defined discrete distribution derived from historical occurrence data, scrap rates are from user-defined discrete probability functions derived from historical data, and the number of units required for a particular quarter are drawn from a user-defined discrete probability function derived from historical induction data. In the case of Navy repair depots sufficient machine capacity is not an issue since depots are designed to handle surge demand in the case of a full-scale conflict.

The control system used by synchronous manufacturing is drum-buffer-rope (DBR). DBR is to provide synchronization of all resources without having to actively control each resource (Umble & Srikanth, 1990). The purpose of the drum is to exploit the constraint of the system, where a constraint may be a resource, market demand, scarce raw material, or a managerial constraint (Schragenheim & Ronen, 1990). In the depot environment, since there are no resource constraints, the schedule of parts arriving to the final assembly area paces the operations and acts as the drum. Buffers are intended as protection from disruptions (Schragenheim & Ronen, 1990). In the case of depots, protection from possible disruptions to the scheduled completion of units is needed. The disruptions to the planned flow times may take the form of late parts due to routing delays, scrap, and rework time at any individual operation. Buffers are needed only in critical areas which require protection from these disruptions (Schragenheim & Ronen, 1990).

Finally, the rope is a mechanism designed to force all of the parts of the system to work at the pace set by the drum (Schragenheim & Ronen, 1990). In the model of depot operations the rope pulls parts into the repair shops to ensure that all parts are at the final assembly area at the correct time. The DBR approach to scheduling is a systems approach to planning, scheduling and controlling operations. DBR takes a global view of the depot facility, with each department schedule set to support the reassembly of the gear box.

Schragenheim and Ronen (1990) list three basic steps for scheduling using DBR: (1) Schedule the constraint, (2) Determine the buffer sizes, and (3) Derive the materials release schedules according to the first and second steps. The material release determines the departmental workloads. There are managerial policy constraints regarding the number of shifts used in a particular shop, the frequency of transportation between buildings and the use of efficiency-based performance measures. However, the primary constraint used to drive the drum in the simulation model is the arrival of parts to the final assembly area. This is because of the stochastic nature of routings and processing times and, as a result, parts arriving to the final assembly area often have to wait for other parts before re-assembly can begin.

Assembly buffers provide protection against disruptions that occur while a part is in route to the final assembly area. The buffer provides a means to monitor the arrival of parts to the final assembly area, and provides anticipatory feedback on parts requiring expediting. This provides control, in the form of buffer management, for shop floor operations by comparing the schedule of parts expected to be at the final assembly area with the inventory of parts actually at the final assembly area. This enables shop floor personnel to recognize that a part is running late and expedite it before a disruption occurs. This system provides a major improvement over traditional intermediate-due-date systems which provide feedback only when an intermediate date is missed.

In the simulation models a variety of buffer sizes are evaluated. The size of the buffers in a stable environment is normally defined as three times the average lead time to the constraint (Schragenheim & Ronen, 1990). The determination of buffer sizes in the depot model is done in a different manner. There is a high degree of uncertainty as to required routings and duration of operations, factors not found in traditional manufacturing environments. The rule tested required that the buffer size for each individual part be determined by a constant which is then multiplied by the minimum cumulative processing time, based on part history, (exclusive of any idle time) for the individual part. The model was run with a variety of buffer sizes beginning with small constants and increasing the multiplier until system performance measures begin to deteriorate. The buffer sizes tested used constant multipliers of 3, 4.5, 7.5, 8.5, 9.5, 10.5 and 11.5.

Material release schedules for individual parts are dictated by the buffer size for that part. After a unit is inducted and disassembled, individual parts go to holding areas where the parts await release onto the shop floor. The release of parts onto the floor is paced so that parts with longer expected processing times are released earlier and parts with shorter expected processing time are released later. This staggering of the release, along with buffer management provides a higher degree of control and improved performance.

9 PRESENT PRODUCTION SYSTEM MODEL

The model of present production planning, scheduling and control is derived directly from information gathered at the depot. The model of present policies and procedures is designed to reflect as closely as possible the methods currently used by the Navy and the results of these policies and procedures.

Units are inducted by a level schedule and sent directly to the repair shop after disassembly. The repair shop resources attempt to batch parts, if possible, to save set-up times. Expediting of parts is done reactively; only after the part has caused a delay in the final assembly area will the part be expedited. Transportation of parts from one building to another is done on a daily frequency in order to batch the parts and avoid carrying less than a full truck load from building to building.

10 SIMULATION RESULTS AND ANALYSES

The simulations runs compares the effect of various buffer sizes, and the present operating system, on system performance measures. Later the results from all sets of comparisons are discussed and presented graphically. All of the hypotheses were tested by using two-tailed paired-difference t-test with $\alpha = .10$.

The buffers were used to implement buffer management in the simulation model by dictating the time of release of individual parts and the expediting of parts. In a DBR environment, buffer management is designed to give visibility to parts which may potentially disrupt the constraint (assembly) schedule. If a part has not arrived to the final assembly area by the time half of the total time at the buffer has elapsed (the midpoint of region II), the part may disrupt the final assembly schedule and should be expedited. In order to calculate the buffer size, delay until release, and delay time until the buffer is checked for the part the following formulae were used:

$$BS_i = MULT \times \sum_{j=1}^{m} PT_j \qquad (2)$$

$$DRT_i = \max\{BS\} - BS_i \qquad (3)$$

$$DBC_i = .5 \times \left(BS_i + \sum_{j=1}^{m} PT_j \right) + DRT_i \qquad (4)$$

Where:
DRT_i = delay time until release of part i
BS_i = buffer size for part i (i=1,2,...,9)
DBC_i = delay until the buffer is checked for part i
Max{BS} = maximum time in set BS
PT_{ij} = minimum processing time for operation j on part i
MULT = constant buffer size multiplier

11 SELECTION OF BEST BUFFER SIZE MULTIPLIER

Using DBR with any of the buffer size multipliers lead to significantly better performance overall. Out of the buffer size multipliers tested, a buffer size multiplier of 9.5 produces the best performance for the two primary performance criteria used by the Navy. The response curves in Figure 1 and Figure 2 show that a buffer size multiplier of 9.5 minimizes the mean percent of time completion to schedule is not met and minimizes the number of units which exceed the allowable TAT. A buffer size multiplier smaller than 9.5 leads to poorer performance, as does a buffer size larger than 9.5. Figure 3 shows that as buffer size multipliers becomes larger the need to expedite parts decreases. This is because as the buffers become larger the parts have more time to reach the final assembly area before expediting is necessary. The larger buffer sizes also lead to increased mean time-in-system (Figure 4) and increased mean WIP levels . There appears to be a point at which larger buffer size multipliers cause a decrease in system performance. As buffer sizes become larger the system has more time to cope with the variability in routings and processing times. There is an upper limit on effective buffer size multipliers. As buffer sizes become too large, parts are released into the system earlier and as a result WIP increases
The larger buffer sizes have to expedite fewer parts, but may have to expedite too many parts at once. This may be especially true early in the quarter when many units may be released at once.

In effect, a larger buffer size is more stable in terms of expediting parts, but not effective at coping with waves of late parts requiring expediting. A smaller buffer size is more reactive in terms of expediting, but the increased frequency of expediting leads to disruptions to the system by expediting parts before the parts is really needed to produce units within the allowed TAT. Expediting parts too frequently disrupts the system and tends to generate more expediting which further disrupts the system.

Overall, it appears in order to cope with the large amount of variability in this environment that a buffer size multiplier of 9.5 performs best. There appears to be a relationship between the variability of the routing length, processing variability and buffer size multiplier. The greater the variability, the larger the buffer size multiplier needs to be to effectively control the shop.

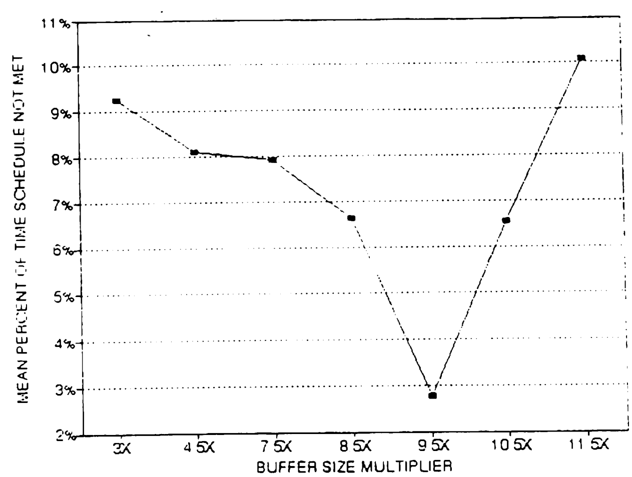

Figure 1: Comparison of the Effect of Buffer Size Multipliers on Completion to Schedule

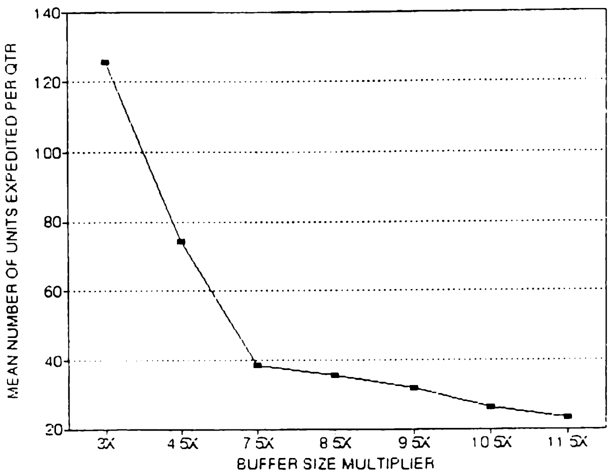

Figure 2: Comparison of the Effect of Buffer Size Multiplier on the Number of Units Expedited

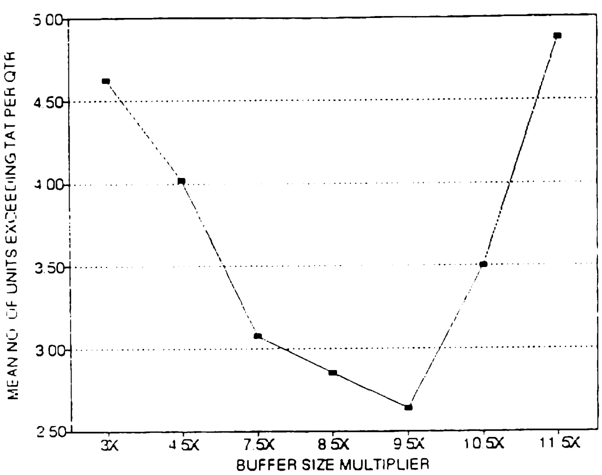

Figure 3: Effect of the Buffer Size Multiplier on the Number of Units Exceeding Allowed Turn-Around-Time

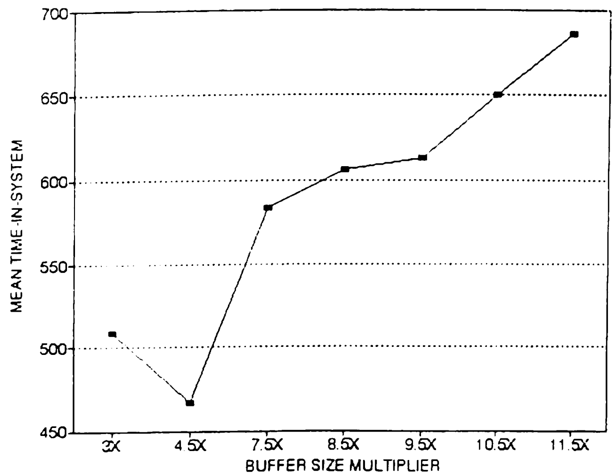

Figure 4: Effect of the Buffer Size Multiplier on Time-in-System

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