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A New Approach of Modeling of Failure-Prone FMSs using Closed-Loop Production Lines

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ABSTRACT

A new approach to model failure-prone FMS is by first decomposing it into a group of closed-loop production lines. To evaluate this approach, the decomposition method of Frein et al (1996) was extended to incorporate failures with repair times having a generalized exponential distribution. It combined and then extended the work of Dallery et al (1988, 1989), Frein et al (1996), and Dallery and Bihan (1999). The FMS was treated here as a group of disaggregated non-homogeneous closed-loop production lines. Each non-homogeneous closed-loop production line was analyzed and subsequently results obtained from them were aggregated to give performance parameters of the FMS. A simulation study was done to validate the results.

Key words: Model failure-prone FMS, closed-loop production lines, decomposition method

INTRODUCTION

In this research, the failure-prone FMS (Fig. 1) is approximated by a group of automated closed-loop production lines. The process harnesses several recently published results. A routing policy decides which particular line a part will go to. The overall behaviour of such a conglomerate would depend on the performance of the individual production lines constituting it. Each such closed-loop production line is configured here as a sequence of machines (Fig. 2), the sequence containing one or more machines of same type or different type. Finite sized buffers separate the machines in the line. Parts flow from one machine to the next machine along the line. Each part spends a fixed amount of time called the processing time on a machine. This processing time may differ from machine to machine. Further, repair times in the present work are assumed to have generalized exponential distribution. The individual machines are prone to failure caused by events such as equipment breakage, missing parts, tool wear, operator error, and quality problems. These failures influence the performance of closed-loop production lines. When a machine fails, it is unavailable for an amount of time required to repair it. This time is known as repair time or downtime of the machine.

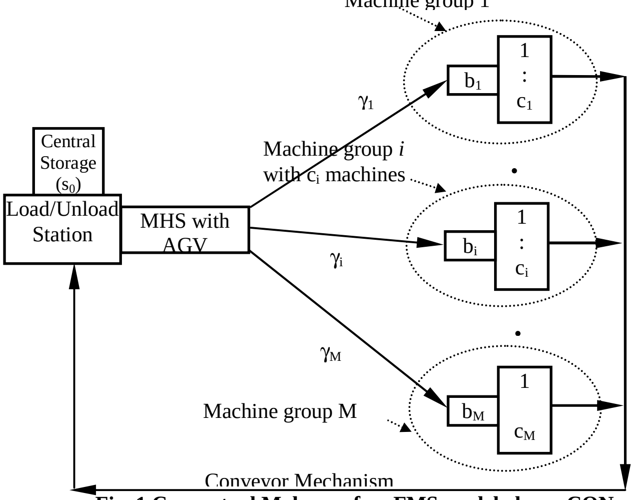

Fig. 1 Conceptual Makeup of an FMS modeled as a CQN

In a closed-loop production line, when a machine is in a failed state, the number of parts in the upstream buffer tends to increase while the number of parts in the downstream machine tends to decrease. If the failure condition persists, the upstream buffer may become full and consequently, the upstream machine may be blocked. Similarly, the downstream buffer may become empty and, therefore, the downstream machine may be starved. Hence, the failure of a machine may lead to starvation and blocking of its adjoining machines. Most failures of production lines are operation-dependent rather than time dependent i.e. failures occur only when the machine is working (Buzacott and Hanifin, 1978) and also machines cannot fail when they are fully starved or fully blocked. A machine is blocked if on completion of the processing of a part, the downstream buffer is full.

Scope and Organization

This research adopts a different approach to model a failure-prone FMS—it uses closed-loop production lines. Section 2 introduces the closed- loop production lines nomenclature and it reviews past related work. Here, the manner in which an FMS is decomposed into several different closed-loop production lines is illustrated (see Fig. 2). Section 3 describes the method for analyzing non-homogeneous production lines. Two methods are presented. Section 4 shows how the closed-loop production lines model may be developed by employing transformations. Section 5 presents the computational algorithm for modeling an FMS using closed-loop production lines. Section 6 describes the use of this model in performance evaluation. Section 7 presents numerical results of a failure-prone FMS model.

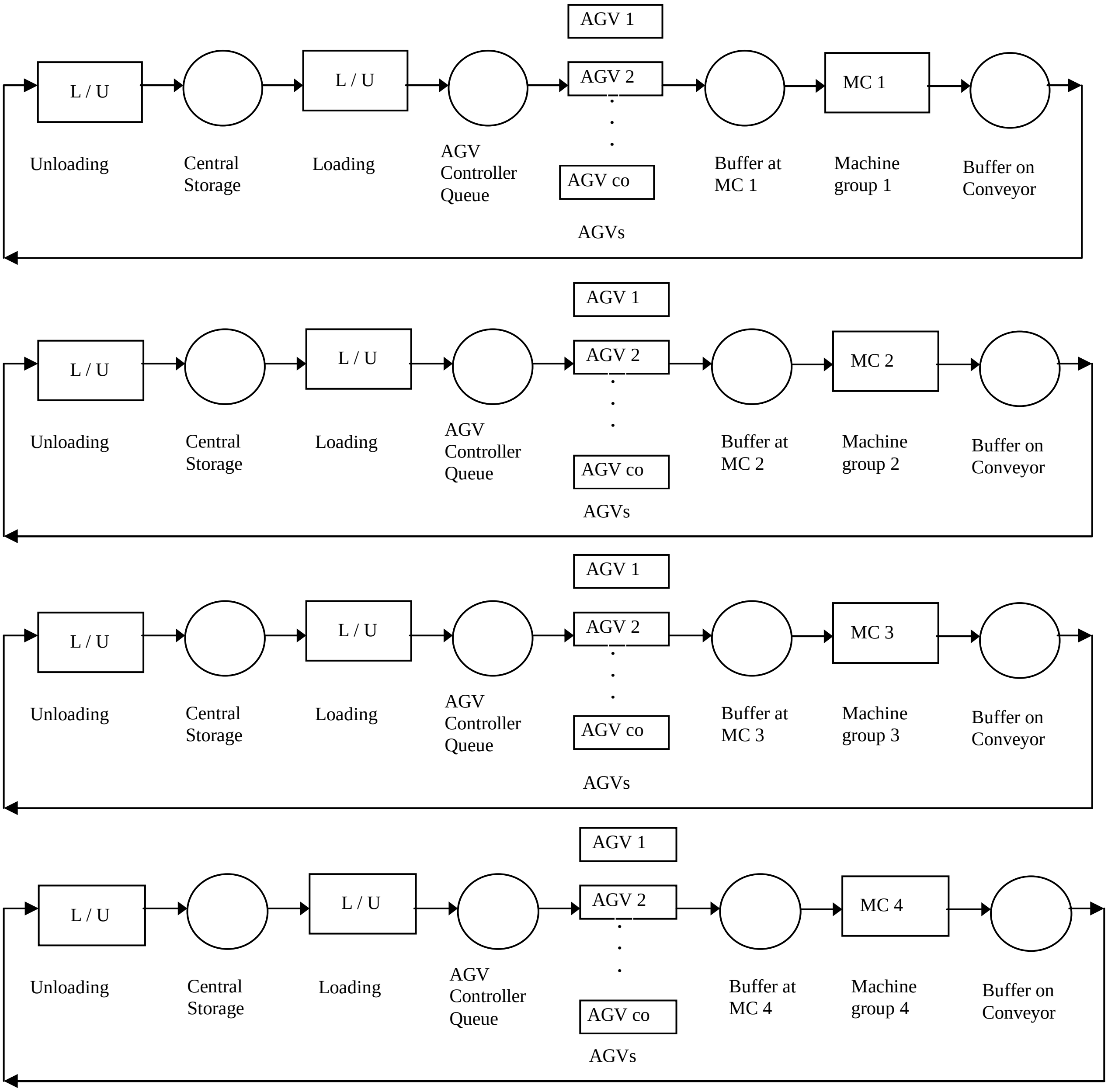

Fig. 2 Decomposition of the FMS into four closed-loop production lines

Introduction to Closed-Loop Production Lines

Let us consider a closed-loop production line *j* consisting of a series of n_j machine groups $\left(MC_1^j, MC_2^j, ..., MC_i^j, ..., MC_{n_j}^j\right)$ separated by n_j buffers $(B_1^j, B_2^j, ..., B_i^j, ..., B_{n_j}^j)$ having finite buffer capacities $(b_1^j, b_2^j, ..., b_i^j, ..., b_{n_j}^j)$ (details of the various indices are given below).

Indices used in this research are defined as follows:

Index	Characteristic represented
h	: homogenized (line)
j	: production line
i	: machine in a production line
e	: generalized exponential (GE)
u	: upstream machine
d	: downstream machine

A new part entering the system from outside is mounted on a pallet. The pallet carries it to machine group MC_1^j, then to buffer B_1^j, then to machine group MC_2^j, and so on, until it reaches buffer $B_{n_j}^j$, after which the pallet goes back to MC_1^j where the finished part is removed and the pallet is reused for another new part. Assume that there are always new parts available at the input of the system and unloading space available at the output of the system. Pallets are used to carry parts throughout the production line. As is the case with closed loop queueing network (CQN), it is assumed here that a limited number N of pallets keep recirculating in the system. A new part is released to the system only if a pallet is available at the load/unload station. The part is then loaded onto the pallet and remains on it during its sojourn in the system. When the last operation has been performed, the part is unloaded and the pallet becomes available to carry a new part. It is assumed that the FMS produces only one type of parts, though they may each require differing amounts of processing. There is no rework or rejection. Each buffer is connected to exactly two machines MC_i^j and MC_{i+1}^j, and is named B_i^j.

In general, the time that parts spend on machine groups is random. This randomness may be due to variability in processing times and/or failures of the machine groups. Owing to this variability in processing times of the machine groups, FMS are represented using non-homogeneous lines. However, processing times are assumed at a machine group to be deterministic, but the time-to-failure of the machine group is exponentially distributed.

A machine group may fail only when it is processing a part. Thus, failure is operation-dependent. The time-to-failure is exponentially distributed. Let f_i^j be the failure rate of machine group MC_i^j. Its mean time to failures (MTTF) is thus $1/f_i^j$. Since, operation-dependent failures are considered, $1/f_i^j$ is the average working time of machine group MC_i^j between two failures. After a machine group has failed, it is put under repair. Repairing times are also exponentially distributed. Let r_i^j be the repair rate of machine group MC_i^j. Its mean time to repair (MTTR) is therefore $1/r_i^j$. It is assumed that when a failure occurs, the part stays on the machine group, and that processing resumes after the repair is completed, i.e., '*preemptive-resume policy*' is in effect. When machine group MC_i^j is in a failed state, the number of parts in buffer B_{i-1}^j tends to increase while the number of parts in buffer B_i^j tends to decrease as the parts move from it to next machine group MC_{i+1}^j. As said earlier, if this condition persists, buffer B_{i-1}^j may become full, and if machine group MC_{i-1}^j completes a part, it will be blocked and therefore prevented from working. Similarly, buffer B_i^j may become empty. In that case, machine group MC_{i+1}^j is starved and therefore prevented from working. It should be noted that, since operation-dependent failures are being considered, a machine group might fail only if it is neither blocked nor starved. Note also that MC_1^j is never starved and machine group $MC_{n_j}^j$ is never blocked as it is assumed that new parts are always available at the input of the system and space is available at the output of the system.

Such systems are difficult to analyze because of their large state spaces and their un-decomposability. The method used in this research is based on the model that approximates the n_j-buffer system by n_j *individual* buffer systems. The parameters of the single buffer systems are determined by the relationships existing among the flows through the buffers of the original system. The calculation of throughput and average levels is difficult because of the great size of the state space. Each machine group can be in four states: operational, blocked, starved, and under repair. Buffer B_i^j can be in b_i^j+1 states (the content of the buffer can have values from 0 to b_i^j where b_i^j is its maximum capacity). Consequently, the Markov chain representation of n_j machine groups closed-loop production line with n_j buffers has a state space of cardinality $4^{n_j}\prod_{i=0}^{n_j}(b_i^j+1)$.

This state space is too large to allow brute force calculation. The approximate decomposition algorithm described below reduces this effort considerably.

The two-machine transfer line, i.e., a line consisting of only two machines separated by a finite buffer, has been extensively studied in the literature. The usual assumptions are that both the time-to-failure and the time-until-repair is complete are exponentially distributed. However, even in this simple case, no exact solution has yet been derived. As a result, two approximate models have been suggested for it, called respectively the *discrete model*, and the *continuous model*.

Both approximate models provide very accurate results provided that the time between failures and the time until repair is complete are much larger than the processing times. This condition holds in many applications and is true in the case of FMSs.

Many researchers have analyzed the longer transfer lines. Gershwin and Schick (1983) have derived an exact solution for the three-machine version of the discrete model. However, it appears that 'it is difficult to program, ill-behaved, and not extendable to larger problems' (Gershwin, 1987). Therefore, a solution for transfer lines with more than two machines would require approximations. Two different types of approximate techniques have been proposed so far to solve transfer line problems. These are named, respectively, *decomposition methods* and *aggregation methods.*

Frein, et al. (1996) proposed an analytical method to evaluate the performance of closed loop production lines with unreliable machines and finite buffers. The principle of this method is to decompose the j^{th} n_j-machine homogenized closed-loop line called L^j into a set of n_j two-machine open lines tagged L_i^j, i = 1, ..., n_j. Each line L_i^j is a continuous-flow model consisting of an upstream machine, MC_{iu}^j , a downstream machine MC_{id}^j , and an intermediate buffer, B_i^j . In this method the repair time distribution of machine M_{iu}^j and M_{id}^j is approximated by an exponential distribution with the same mean.

Le Bihan (1998) describes several homogenization methods for tandem lines. These methods can be extended to assembly/disassembly systems, so that the original non-homogeneous tree-structured system is transformed into a homogeneous one, which is then analyzed by the methods of Gershwin (1991) or Di Mascolo, David, and Dallery (1991). Dallery and Bihan (1999) proposed another approximation technique for the analysis of open type of transfer lines. The processing times are deterministic and all the machines have the same processing time. They use two-moment approximation instead of a one-moment approximation of the repair time distribution for equivalent machines. The literature summarized above indicates that little is available yet for analyzing maintainability and reliability of the FMS using closed-loop production lines. This research is an attempt to extend previous research on modeling of closed-loop production lines into the modeling of failure-prone FMSs.

In this research, an FMS such as the system shown in Fig. 1 consisting of M machine groups is modeled as a group of M closed-loop production lines. Each production line is analyzed using an extended decomposition technique. This extended decomposition technique developed in this research uses the generalized exponential distribution (two-moment approximation) for repair time distribution of MC_{iu}^j and MC_{id}^j machines. Use of generalized exponential distribution was suggested by Dallery and Bihan (1999) for open transfer lines. It was noticed by Dallery and Bihan that the original decomposition method by Frein et al. (1996) for closed-loop production lines, may not give accurate results for those cases where the reliability parameters (mean times to failure and repair) are of different orders of magnitudes. This weakness in the method due to Frein et al. is addressed in the present work by using generalized exponential distribution in place of exponential distribution for repair time distribution of machines. This technique was used in this research for the reliability analysis and modeling of a failure-prone FMS.

In Fig. 2 the central server model of FMS (Fig. 1) has been conceptually disaggregated into a group of closed-loop non-homogeneous production lines. Each resulting non-homogeneous production line is then separately analyzed. These non-homogeneous lines are converted into homogeneous lines. To illustrate this adaptation a hypothetical FMS is used (shown in Fig. 1) that has four machine groups each having single-machine capability. This FMS is decomposed (consisting of a load/unload station, a central storage, an AGV controller, AGVs, machine groups with finite buffer capacity and a conveyor system) into a set of closed-loop production lines. Note that in the situation modeled, the load/unload station, AGVs and machine groups, all are prone to failure. The FMS such as the system shown in Fig. 1 consisting of M machine groups is decomposed into M closed-loop production lines. Each j^{th} $\left(j\in[1:M]\right)$ closed-loop production line in the decomposed system consists of load/unload station, central storage, AGV controller with AGVs, one machine group and conveyor system as shown in the Fig. 2.

Analysis of Non-Homogeneous Production Lines

Let T_i^j be the processing time at node MC_i^j (ith node in jth line). One way of analyzing a non-homogeneous line is to transform it into a homogeneous line. This transformation is called as *disaggregation*. Dallery et al. (1989) proposed another transformation of a non-homogeneous production line to a homogeneous production line. This transformation known as *homogenization* is simpler and leads to results that are closer to simulation. This transformation is used in the present work. It replaces each machine of the original line by an equivalent single machine as described below.

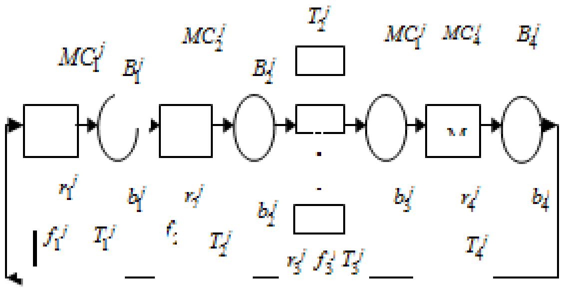

Fig. 3 Original system parameters of jth non-homogeneous production line

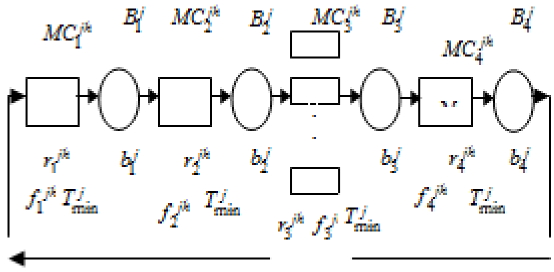

Fig. 4 Homogeneous jth production line consisting of four buffers

All the equivalent machines have identical processing times $T_{\min}^j$, which is equal to the processing time of the fastest machine of the original line (Fig. 3). Thus $T_{\min}^j$ is given by the minimum of $\left\{T_1^j, \ldots, T_{n_j}^j\right\}$. Let f_i^{jh} and r_i^{jh} be the failure rate and repair rate of the equivalent machine of machine MC_i^j in jth homogenized production line (Fig. 4). The parameters f_i^{jh} and r_i^{jh} must be chosen such that the behavior of the homogenous line is close to the behavior of the original nonhomogeneous line.

Thus in this transformation the failure rate of the node is adapted to the new speed of the node while its repair rate remains the same (Fig. 4).

Model Development

In this section, the approach is developed that will be used in modeling FMSs using closed-loop production lines. As stated earlier the FMS is first decomposed into a group of non-homogeneous closed-loop production lines. Using the procedure given in Section 3 these non-homogeneous lines are transformed into homogeneous lines. Each homogeneous line is then analyzed by the extended technique developed in this research. The method of Frein et al. (1996) is expanded in this research by approximating the repair time distribution by a generalized exponential distribution.

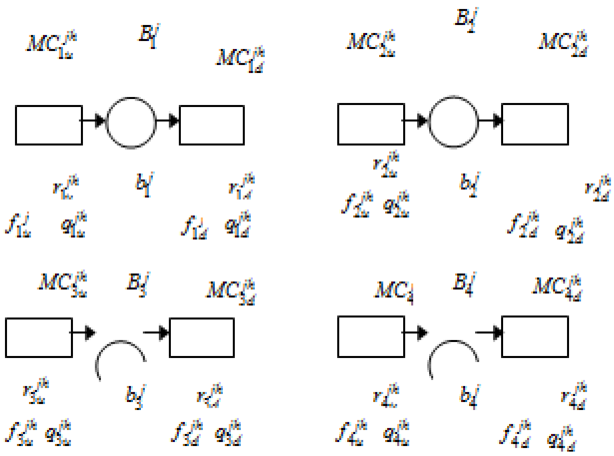

Fig. 5 Decomposition of the Homogeneous jth Production Line (Fig. 4) into Four Two-Machine Lines

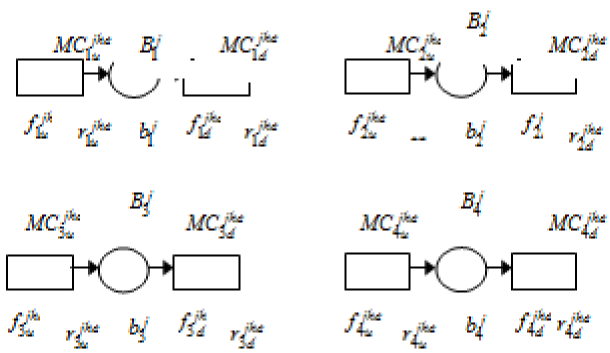

Fig. 6 'Equivalent' Four Two-Machine Lines of Fig. 5

It is important to note that in the present analysis the processing times are assumed to be *deterministic*. Each line L_i^{jh} must be defined in such a way that the behavior of the material flow in buffer B_i^j closely matches that of the material flow in buffer B_i^j of the line L^{jh}.

The homogeneous j^{th} Production Line L^{jh} consisting of four buffers shown in Fig. 4 would thus be decomposed into four two-machine lines $\{L_1^{jh}, L_2^{jh}, L_3^{jh}, L_4^{jh}\}$ as shown in Fig. 5. Machine MC_{iu}^{jh} represents (in an aggregate way) the part of the line upstream of buffer B_i^j, while machine MC_{id}^{jh} represents (in an aggregate way) the part of the line downstream of buffer B_i^j.

In addition, machine MC_{id}^{jh} models how material is transferred out of buffer B_i^j. In this method the repair time distribution of machine MC_{iu}^{jh} and MC_{id}^{jh} is approximated by an exponential distribution with the same mean (one moment approximation). This condition is modified by approximating the repair time distribution of machine MC_{iu}^{jh} and MC_{id}^{jh} by the generalized exponential distribution (two moment approximation) in this research. The performance parameters for the homogeneous j^{th} production line are defined as follows:

E_i^{jh} efficiency of machine group MC_i^{jh} i.e. the proportion of time machine group MC_i^{jh} is working;

ps_i^{jh} probability that machine group MC_i^{jh} is starved in homogeneous j^{th} line;

pb_i^{jh} probability that machine group MC_i^{jh} is blocked in homogeneous j^{th} line;

Q_i^j average amount of material in buffer B_i^j in homogeneous j^{th} line;

After approximating the repair time distribution of machine MC_{iu}^{jh} and MC_{id}^{jh} by generalized exponential distribution and taking the above equivalence with exponential distribution the performance parameters are calculated. The performance parameters of interest, E_i^{jh}, ps_i^{jh} *and* pb_i^{jh} for a homogeneous j^{th} line L^{jh} may be obtained by solving *equivalent* two-machine groups lines L_i^{jhe}, $i \in [1:n_j]$ with exponential failure and repair time distributions. Fig. 6 shows the equivalent four two-machine lines for the four two-machine lines of Fig. 5.

Using the above quantities $f_{iu}^{jhe}, r_{iu}^{jhe}, f_{id}^{jhe}$ *and* r_{id}^{jhe}, the parameters E_i^{jhe}, ps_i^{jhe} *and* pb_i^{jhe}, as well as the average buffer level Q_i^j are calculated (Gershwin and Schick, 1983 and Dallery, David and Xie, 1989). The change in the present study is the introduction of homogenization approximation for non-homogeneous closed-loop production lines, which extends the works of earlier researchers. The efficacy of this approximation is validated by simulation.

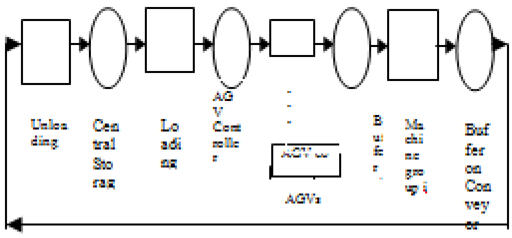

Fig. 7: i^{th} Closed-Loop Production Line of the FMS as Shown in Fig. 1

To apply decomposition approach to a failure-prone FMS the procedure is as follows:

- Transform an FMS first into j multiple transfer lines as shown in the Fig. 2. Fig. 2 displays four closed-loop production lines for the FMS described in Fig. 1. The procedure begins by specifying the number of machine groups and material handling vehicles (AGVs) in the system, along with the routing probability (all parts are identical and require same processing sequence) to each machine groups. AGVs in the original FMSs collectively serve each decomposed closed-loop production line. However, their availability at a particular production line depends upon (a) the number of AGVs in the system, (b) the failure behavior of the AGVs. The equivalent individual decomposed production line would consist of one unloading/loading station, a central storage, one AGV controller, one machine group and a conveyor system (Fig. 7). Parts are mounted on the pallets. Pallets move in the production line. N represents the limited number of pallets circulating in the system. A new part can be released to the system only if a pallet is available. The part is then loaded onto the pallet and remains on it during its sojourn in the system. When the last operation has been performed, the part is unloaded and the pallet becomes available to carry a new part.

The flow of pallet is modeled as follows. A part mounted on the pallet during one production cycle traces the following path (Fig. 7):

- First, a finished Part, which has come from conveyor to the L/U station, will be unloaded. The pallet will remain engaged during unloading or in other words processing has been done on the pallet and pallet spends some time on node. Finished part goes out. The free pallet moves on to central storage. Note that there is a failure behaviour associated with L/U station.

- Next, the pallet moves on to L/U station for loading of a part on it. There is a loading time associated. The pallet remains engaged and spends time on the L/U station equal to loading time.
- Next, the pallet with the part joins the AGV controller queue. There are alternate AGVs competing for the pallet to be picked up by them to transport it to the buffer of machine group i. Each AGV is equipped to handle one pallet at a time.

The routing policy/protocol governing the FMS operation decides to which machine group (this corresponds to one of the 4 production line) the part will go. In other words, the traffic intensity to any machine group is decided by the routing scheme. The state dependent routing policy developed here dictates that parts are not sent to 'full buffer' and the 'down' machine groups. Routing probability in effect reflects the number of times a part goes to a particular machine group (a closed loop line) and the interaction between the lines.

- Next, the part on a pallet goes to the machine group for processing. After getting processed it goes back to unloading station via the conveyor buffer for unloading and the freed pallet is transferred to central storage. The sum of the number of parts in each buffer is always equal to total number of pallets.

The above transformation of FMSs into multiple independently operating transfer lines is one alternative method for analyzing the FMS. The lines interact through the routing scheme in affect. Such a model can also provide a basis for comparing the performance between two or more different FMSs design/operation configurations. Each disaggregated closed loop production line is analyzed using the algorithm described in next section. However, this analysis is valid only when processing times are deterministic.

Computational Algorithm

The algorithm to evaluate a closed-loop line consists of two major 'loops'. For a given value of I_{1u}^{jh}, the inner loop solves the system of $4n_j$ - 1 equations. An iterative procedure is used whose convergence criterion is the conservation of parts flow through the homogeneous j^{th} production line. The outer loop seeks the value of I_{1u}^{jhe} such that the sum of the number of parts in each buffer is equal to the total number of pallets in the closed-loop production line, i.e., $\sum_{i=1}^{n_j} Q_i^j = Q^j = N$ is satisfied. This is achieved by using a binary search.

Performance Evaluation of the FMS

Many real FMSs are composed of a load/unload station, a set of machine groups with local buffers, a material handling system (MHS) and a common central buffer. Each machine group includes a limited input buffer, several machines (servers), and a limited output buffer, which is optional. A machine group takes a part from the input buffer, processes it, and then releases it to the output buffer or to a conveyor. The MHS consists of several AGVs moving parts among the machine groups according to the process paths required by the parts. The function of the common buffer is to temporarily store blocked parts. Parts enter the system from the load/unload station, and leave the system through the load/unload station after all required processes are finished. In the present method, in order to obtain the performance parameters of the FMS, it is first conceptually transformed into multiple nonhomogeneous closed loop production lines. Then the efficiency and average part flow time of each production line are approximated by disaggregation and homogenization transformations and the extended decomposition technique shown above.

Numerical results and Discussions

In this section, some numerical results are presented for the model of the failure-prone FMS system developed above. Tables 1 to 8 give the system parameters for the different cases (FMSs characteristics) considered and the comparison between above technique with simulation. A simulation model was built using ARENA for the typical FMSs configuration shown in Fig. 8. The results obtained are compared from the closed loop production lines technique with those obtained by simulation. In each case study, the simulation experiment consisted of ten replications.

For each case the simulation was conducted for 100,000 time units and for each experiment, statistics were collected after the elapse of a warm-up period of 20,000 time units to minimize the effects of initialization. It was ensured that this length was long enough to eliminate the initialization bias and to provide independence (of the performance measure in question) between the successive replications of a simulation run. At the end of each replication, the model calculates a 95% confidence-interval half width for the steady-state (long run) expected value of throughput from each machine group, waiting time at each machine group, queue length at each machine group and utilization of each machine group. A simulation model was also built for a single closed-loop production line to compare the results obtained using the extended algorithm developed in the Section 5 for closed-loop production lines and those of simulation. The results from extended algorithm developed in this research agree well with simulation results.

For all case studies the convergence tolerance $\in = 10^{-4}$ was set. Generally, the algorithm converges fast but the number of iterations needed to reach convergence depends on $\in$ and system parameters. This fact was noticed during trial runs. For each case study carried out, the above extended decomposition technique demonstrated reasonable accuracy. The relative errors are generally no more than 5% for throughput and only in few cases higher than 10% but less than 15%.

While experimenting with the above model, one observation regarding production efficiency (rate) and the excess capacity (Excess capacity is the difference of total capacity of the buffer and pallet number) for a closed-loop production line (Fig. 9) was noticed. The total buffer capacity is kept constant and the number of pallets circulating in the production line is changed. It is observed that the relation between the production rate and the excess capacity of buffer is a non-linear relationship that grows with marginally diminishing rise in efficiency. Beyond a point, even if there is excess buffer capacity installed there is no significant increase in the production rate. Hence, an optimum number of pallets may give the desired maximum production rate. It is assumed that there are always parts available at the input of the system and space is available at the output of the system. As a result, the behavior of this system is entirely determined by the behavior of the pallets circulating through the closed loop.

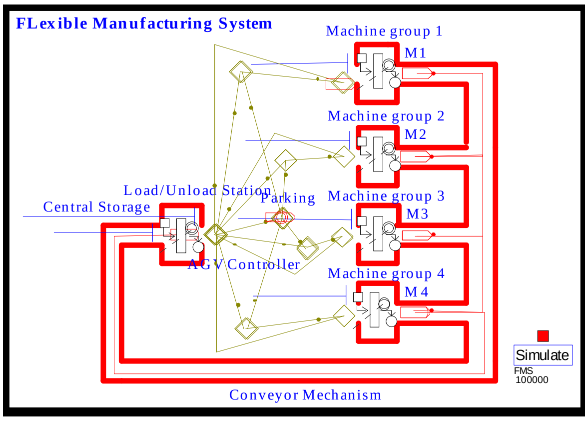

Fig. 8 ARENA Diagram of the Conceptual FMS

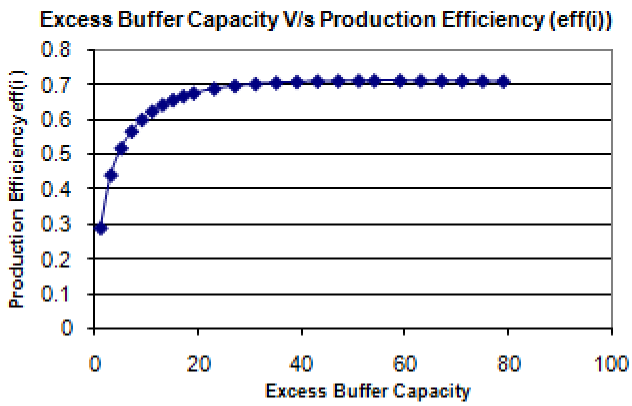

Fig. 9 Result for a closed-loop production line

In case 1 (Table 1), single machine at each machine group is available with different buffer capacity. Each machine group has the same processing capacity. The throughput from each machine group now depends upon the routing probabilities.

On reducing the number of AGVs 4 in case 1 (Table 3) to 3 in case 4 (Table 8) it is found that this action reduces the total mean throughput of the system by 6.5 %. This is due to starvation of machine groups, since traffic intensity is affected by lowering the number of AGVs in use.

When failure rates of the machines at the machine groups are increased (case 2 (Table 4) from 0.001 to 0.01 in case 3 (Table 6)) the total mean throughput of the system is reduced (Table 6), again as expected. Similar relationships were observed in other numerical experiments also. It is inferred that the model developed is able to reasonably model a FMS and hence may be used in the performance analysis of the system. It is planned to explore the possibility of modeling multi-machine machine groups using above technique in future.

Table -1 Case 1 System parameters for the FMS

M/c No.	Service rate	Machines	Buffers	Routing rate	Failure rate	Repair rate
1	1	1	4	0.15	0.001	0.1
2	1	1	6	0.10	0.001	0.1
3	1	1	8	0.35	0.001	0.1
4	1	1	10	0.40	0.001	0.1
L/U station	1	1	20	1	0.001	0.1

Number of AGVs = 4; AGV speed = 1; Number of pallets = 30
Buffer Capacity of Central Storage and conveyor is 20 each
AGV failure rate and repair rate are 0.001 and 0.1 respectively

Table -2 Throughputs for Case 1

M/No.	Simulation Throughput (A)	Analytical E(i)	Analytical γ_i^{eff}	Analytical Throughput (B)	Error (B-A)*100/B	Computational Time Analytical (Sec)	Computational Time Simulation (Sec)
1	0.14851 ± 0.00197	0.957829	0.151549	0.14520	-2.28%	0.21978	14800 (10 replications)
2	0.09896 ± 0.00217	0.960041	0.101131	0.09709	-1.93%		
3	0.34544 ± 0.00248	0.961765	0.350005	0.33670	-2.59%		
4	0.39376 ± 0.00175	0.963124	0.397314	0.38270	-2.89%		

Table -3 Case 2 System Parameters for the FMS

M/c No.	Service rate	Machines	Buffers	Routing rate	Failure rate	Repair rate
1	1	1	4	0.25	0.001	0.1
2	1	1	6	0.25	0.001	0.1
3	1	1	8	0.25	0.001	0.1
4	1	1	10	0.25	0.001	0.1
L/U Station	1	1	20	1	0.001	0.1

Number of AGVs = 4; AGV speed = 1; Number of pallets = 30
Buffer Capacity of Central Storage and conveyor is 20 each
AGV failure rate and repair rate are 0.001 and 0.1 respectively

Table -4 Throughputs for Case 2

M/No.	Simulation Throughput (A)	Analytical E(i)	Analytical γ_i^{eff}	Analytical Throughput (B)	Error (B-A)*100/B	Computational Time Analytical (Sec)	Computational Time Simulation (Sec)
1	0.24672 ± 0.0031	0.957829	0.249099	0.238590	-3.40%	0.21978	12000 (10 Replications)
2	0.24812 ± 0.0011	0.960041	0.250119	0.240124	-3.33%		
3	0.24867 ± 0.0027	0.961765	0.250361	0.240788	-3.27%		
4	0.24866 ± 0.0021	0.963124	0.250421	0.241186	-3.10%		

Table -5 Case 3 System parameters for the FMS

M/c No.	Service rate	Machines	Buffers	Routing rate	Failure rate	Repair rate
1	1	1	4	0.25	0.01	0.1
2	1	1	6	0.25	0.01	0.1
3	1	1	8	0.25	0.01	0.1
4	1	1	5	0.25	0.01	0.1
L/U station	1	1	12	1	0.01	0.1

Number of AGVs = 3; AGV speed = 1; Number of pallets = 30
Buffer Capacity of Central Storage and conveyor is 12 and 14 respectively AGV failure rate and repair rate are 0.01 and 0.1

Table -6 Throughputs for Case 3

M/No.	Simulation Throughput (A)	Analytical			Error (B-A)*100/B	Computational Time	
		E(i)	γ_i^{eff}	Throughput (B)		Analytical (Sec)	Simulation (Sec)
1	0.14329 ± 0.0025	0.504143	0.249811	0.12594	-13.77	0.76923	11040 (10 Replications)
2	0.14417 ± 0.0016	0.569702	0.250075	0.142468	-1.190		
3	0.14639 ± 0.0030	0.613637	0.250109	0.153476	4.610		
4	0.14375 ± 0.0012	0.540517	0.250006	0.13513	-6.38		

Table -7 Case 4 System parameters for the FMS

M/c No.	Service rate	Machines	Buffers	Routing rate	Failure rate	Repair rate
1	1	1	4	0.15	0.001	0.1
2	1	1	6	0.10	0.001	0.1
3	1	1	8	0.35	0.001	0.1
4	1	1	5	0.40	0.001	0.1
L/U station	1	1	12	1	0.001	0.1

Number of AGVs = 3; AGV speed = 1; Number of pallets = 30
Buffer Capacity of Central Storage and conveyor is 12 and 14 respectively AGV failure rate and repair rate are 0.001 and 0.1

Table -8 Throughputs for Case 4

M/No.	Simulation Throughput (A)	Analytical			Error (B-A)*100/B	Computational Time	
		E(i)	γ_i^{eff}	Throughput (B)		Analytical (Sec)	Simulation (Sec)
1	0.14871 ± 0.0015	0.875498	0.151272	0.132438	-12.28%	0.824175	17000 (10 Replications)
2	0.09856 ± 0.0008	0.908045	0.100924	0.09164	-7.55%		
3	0.34542 ± 0.0026	0.925439	0.351425	0.325224	-6.20%		
4	0.39364 ± 0.0033	0.894646	0.396379	0.354618	-11.00%		

CONCLUSION

An approximate modeling technique is explored in this research, which may be used to model large sized failure-prone FMSs with finite buffer size. Note, however, that the above approach applies only to systems with deterministic processing times. It was concluded that while the approach produced acceptable results, its application should be made when the size of the system would make the use of the more near-exact Disaggregation and Aggregation (DA) approach intractable or difficult.

REFERENCES

[1] JA Buzacott and LE Hanifin, Models of Automatic Transfer Lines with Inventory Banks a Review and Comparison, *AIIE Transactions*, **1978,** 10 (6), 197-207.

[2] Y Dallery, and H Le Bihan, An Improved Decomposition Method for the Analysis of Production Lines with Unreliable Machines and Finite Buffers, *International Journal of Production Research*, **1999,** 37 (5), 1093-1117.

[3] Y Dallery and Y Frein, An Efficient Method to Determine the Optimal Configuration to a Flexible Manufacturing System, *Annals of Operations Research*, **1988,** 15, 207-225.

[4] Y Dallery and Y Frein, A Decomposition Method for Approximate Analysis of Closed Queueing Network with Blocking, *Queueing Networks with Blocking, HG Perros and T Altiok (Eds)*, North-Holland, Amsterdam, **1989,** 193-215.

[5] Y Dallery, R David and XL Xie, Approximate Analysis of Transfer Lines with Unreliable Machines and Finite Buffers, *IEEE Transactions on Automatic Control*, **1989,** 34, 9, 943-953.

[6] M Di Mascolo, R David and Y Dallery, Modelling and Analysis of Assembly Systems with Unreliable Machines and Finite Buffers, *IIE Transactions*, **1991,** 23 (4), 315-330.

[7] Y Frein, C Commault and Y Dallery, Modelling and Analysis of Closed-Loop Production Lines with Unreliable Machines and Finite Buffers, *IIE Transactions*, **1996,** 28, 545-554.

[8] SB Gershwin, An Efficient Decomposition Method for the Approximate Evaluation of Tandem Queues with Finite Storage Space and Blocking, *Operations Research*, **1987,** 35 (2), 291- 305.

[9] SB Gershwin, Assembly/disassembly systems: An Efficient Decomposition Algorithm for Tree-Structured Networks, *IIE Transactions*, **1991,** 23 (4), 302-334.

[10] SB Gershwin and IC Schick, Modelling and Analysis of Three-Stage Transfer Lines with Unreliable Machines and Finite Buffers, *Operations Research*, **1983,** 31 (2), 354-380.

[11] H Le Bihan, *Denouvelles Methodes Analytiques Pour L'´Evaluation De Performances De Lignes De Production***,** PhD Thesis, Université Pierre et Marie Curie, **1998**.

[12] WI Zangwill and CB Garcia, *Pathways to Solutions, Fixed Points and Equilibria*, Prentice-Hall, Inc. Englewood Cliffs, NJ **1981.**