DESIGNING A CONSTANT WORK IN PROGRESS PRODUCTION CONTROL SYSTEM

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Abstract: A "Constant Work in Progress" production control system acts by restricting the number of jobs present in a "workshop" at any one time (maximum number n jobs) with the manager determining the "best" value for n. This shows how simulation methods and measures of complexity can be used to design an optimal constant work in progress system for a firm. Section 1 validating the measures of complexity by simulating their performance in small manufacturing firms. Section 2 shows the results from the simulations showing how simulation can be used to derive optimal production control systems.
Keywords: Production Control, Simulation, Measures of Complexity.

1 QUEUEING/DECISION MAKING ENTROPY

The derivation an entropy formula and justification for the use of Entropy to measure complexity is given in Frizelle [Frizelle and Woodcock, 1995] here a simpler version is considered. A simpler version is appropriate because a "Flow Shop" describes the predominant production system in small manufacturing firms.
Consider a manufacturing system consisting of m stages where queues could arise at any of these stages. The firm will make a decision, which job to process next, if at the time when a job is finished at a stage the queue of waiting jobs at the stage is greater than 1.
Therefore the simulation aims to determines and the entropy measure indicate the number of times that a decision is made at each stage, where n_i is the number of decisions at stage i, and $N = \Sigma n_i$ gives the total number of decisions made during the simulation.
Then $p_i = n_i/N$ gives the probability that a decision needed to be made at stage i given that the firm has to make a decision, where N decisions are made during the simulation and n_i at the i^{th} stage.

The "Decision Making Entropy" for the system is now given by

$$E = \Sigma -p_i \ln(p_i)$$

The obvious extreme values calculated by this measure occur when:-

(a) decisions are made at only one stage, for example stage 1 when $p_1 = 1$, and $p_i = 0$ all other I in this case $E = 0$, and the decision maker considers only this first stage, the simplest situation.

(b) decisions are made at all stages with the same frequency when

$n_i = k$, for all i and $N = mk$ in which case

$$p_i = 1/m,$$

and

$$E = \Sigma -1/m \ln(1/m) = \Sigma 1/m \ln(m)$$

giving $E = \ln(m)$ the practical worst case where decisions have to be made equally often at all stages.
Therefore Decision Making Entropy can be represented on a [0,1] scale using the measure

$$DME = E / \ln(m) .$$

where $DME = 0$ implies that all decisions are made at one particular stage, in practice the first stage, and $DME = 1$ implies that decisions have to be made at all stages in the process with equal probabilities.
But because a DME of 1 can be obtained when k is small and hence N is small, no real problem few decisions to make and when k is large when many decisions have to be made this measure cannot be satisfactory when considered in isolation.

1.1 Simulation Results

To validate and evaluate the measures for planning and control complexity in small and larger firms the following manufacturing configurations were simulated. The results assumed that the dominant machine was the first machine, assuming strict dominance $T_1 > T_j$ all $i>1$ where T_j is the average processing time on the j^{th} machine.
From each simulation the following results were collected

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(a) Mean μ
mean process time per job
(b) s.d. σ
standard deviation of process time
(c) s.d./mean σ/μ
(d) Entropy E
(e) Entropy/stage E/m
(f) Mean/average {mean process time}/{sum of average machine times}

The aim being to determine whether or not measures c and e provide alternative approaches to the estimation of system complexity.

1.1.1 n machines in series

Here it is assumed that there is one machine at each stage. The system was simulated with 1, 3, 5, and 10 production stages. The results from these simulations are summarised in the table 1. From these results it can be seen that there is a relationship between parameters c and e, both parameters decreasing as the number of stages increases.

1.1.2 n machines in parallel

Similar results were obtained when configurations with only one stage in the production process, but many processors at the stage, were simulated. The system was simulated with 1, 3, 5, and 10 processors at each stage. The results from these simulations are given in table 2. From these results it can be seen that there is a relationship between parameters c and e.

Stages	1	3	5	10
mean	20.2	48.0	58.5	102.
s.d.	15.2	20.2	20.3	21.0
s.d./mean	0.75	0.42	0.34	0.20
Entropy	0.35	0.69	0.55	0.74
Entropy/stage	0.35	0.23	0.11	0.07
Mean/average	2.52	2.02	1.50	1.36

Table 1: n machines in series

Processors	1	3	5	10
Mean	20.18	11.16	9.62	8.51
s.d.	15.28	5.10	3.18	1.77
s.d./mean	0.757	0.456	0.330	0.208
Entropy	0.353	0.367	0.362	0.341
E/m	0.353	0.122	0.072	0.034
Mean/ave	2.522	1.395	1.202	1.063

Table 2: n machines in Parallel

These results showing that the value given by σ/μ can be used to indicate the complexity of a manufacturing system, in place of the more complex Entropy value..

2 USING SIMULATION TO DESIGN CONSTANT WORK IN PROGRESS SYSTEMS

Consider the typical three stage small manufacturing firm (see figure 1)where jobs arrive at random and the job times at each processor are described by a rectangular distribution.

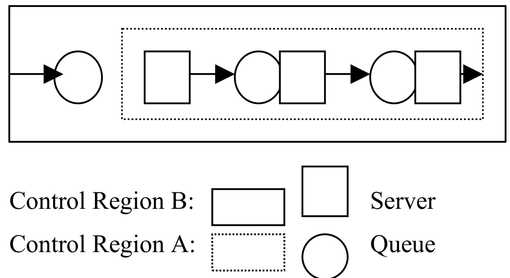

figure 1

To be able to control the workload in region A, the manager needs to be able to determine the number of jobs, n, allowed into the system at any one time.
The number n being chosen to optimise the "cost" of the production system where cost can be expressed as a function of T and C,

$$cost = G(T, C)$$

where

- T is the total time for a job in the system, region B, and
- C measures the complexity in region A, which can be measured by the time a job spends in region A or from the entropy of region A, or more simply from the ratio σ/μ.

Three configurations were simulated, in each the final stage was the dominant stage, longest average job time at this stage,

a) Three stages one processor at each stage,
b) Three stages three processors at each stage,
c) Three stages with five processors at the final stage.

Each of these can be considered to represent a small manufacturing firm. assuming that there is a single worker at each stage then in all cases the number of (production) workers is less than 10.

2.1 Three stages with one processor at each stage F(1,1,1)

This system was simulated with work in progress constraints of 1,2,3,4,5,and 6 jobs. The average time and variance of the average times in region A and B were calculated for each simulation, the results are given in table 3.

Region B				Region A		
wip	μ_B	σ_B^2	σ_B/μ_B	μ_A	σ_A^2	σ_A/μ_A
1	6489	M	0.59	29	4.36	0.07
2	889	M	0.57	29	4.63	0.07
3	**52**	**459**	**0.41**	**33**	**10.79**	**0.10**
4	51.9	449	0.41	39	38.52	0.16
5	51.9	449	0.41	44	102.8	0.22
6	51.9	449	0.41	47	189.1	0.29

Table 3: Comparing entropies

from these results it can be seen that there is no advantage to the firm from setting a limiting WIP_A value greater than 3.

Notice that for $WIP_A>3$

- μ_B is constant, at 52
- σ_B is constant, at 449
- both the mean and the variance of the time in region A start to increase, the system start to become more complex

In this small firm the WIP limit is the same as the number of processors in the system (3) additional jobs remaining in the first queue.

2.2 Three stages F(3,3,3)

This system, representing a larger firm producing the same product type, was simulated with work in progress constraints of 6, 7, 8, 9, 10, 11, and 12 jobs. The average time and variance of the average times in region A and B were calculated for each simulation, the results are given in table 4.
For this firm the WIP it can be seen that the limiting value is “close to” the number of processors in the system, but not necessarily the same.

Region B				Region A		
wip	μ_B	σ_B^2	σ_B/μ_B	μ_A	σ_A^2	σ_A/μ_A
6	249	17967	0.54	28.4	4.22	0.07
7	51.39	309.2	0.34	28.7	4.49	0.07
8	**34.46**	**53.41**	**0.21**	**29.2**	**5.91**	**0.08**
9	**32.5**	**31.5**	**0.17**	**29.9**	**8.04**	**0.09**
10	32.29	29.02	0.17	30.8	12.4	0.11
12	32.26	28.5	0.17	31.9	21	0.14

Table 4: Comparing Entropies

2.3 Three stages F(1,1,5)

This system was simulated with work in progress constraints of 3, 4, 5, 6, 7, 8, 9, and 10 jobs. The average time and variance of the average times in region A and B were calculated for each simulation, the results are given in table 5.
In this firm the WIP limit is (again) not obvious and a means of combining the results from regions A and B, which might involve fuzzy logic for example, would be required to be able to select the optimal WIP value. However it can be stated that the maximum number of jobs allowed into region A at one time will be in excess of 6.

Region B				Region A		
wip	μ_B	σ_B^2	σ_B/μ_B	μ_A	σ_A^2	σ_A/μ_A
3	M	M	0.57	69.3	47.25	0.10
4	M	M	0.56	70.0	51.70	0.10
5	728	M	0.52	71.0	55.70	0.11
6	113	M	0.30	72.0	55.30	0.11
7	**87.0**	**400**	**0.23**	**74.0**	**72.**	**0.11**
8	**83.0**	**282**	**0.20**	**77.0**	**93.**	**0.13**
9	**82.6**	**271**	**0.20**	**79.0**	**130.**	**0.14**
10	82.6	271	0.20	80.9	170.	0.16

Table 5: Comparing Entropies

3 CONCLUSIONS

This investigation has shown that complexity measures can be employed to enable the design an optimal control system for a manufacturing firm and that simulation methods can be used to design this control system.
The results also show that as the firm grows and the production system becomes more complex, more processors at each stage the

parameters for the optimal control system become less obvious. This result emphasises the fact that as firms grow they will need to re evaluate their production control procedures if they wish to continue to operate optimally.

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