Evaluating scheduling policies in a multi-level assembly system

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Article:
This paper orders in preference various scheduling policies comprised of dispatching and regeneration rules in a multi-level assembly production system. Traditional expected-value statistical and second-degree stochastic dominance preference ordering rules are used to identify the most efficient scheduling policies for risk-averse managers using various measures of performance. The results indicate that selection of an efficient regeneration rule is contingent upon the selection of a dispatching rule and these rules must be selected jointly to develop efficient scheduling policies. For this study, simple intuitively appealing scheduling policies were found to be efficient.

Article:

IMTRODUCTION

Owing to the pressures created by the economic environment and the loss of markets to competition from countries throughout the world there is a renewed interest in the theory and practice of production scheduling and inventory man - agement. High interest rates and disinflation have intensified the strategic role of production scheduling in managing the substantial costs of inventories. Additionally, the importance of production scheduling for providing better customer service in terms of minimizing production lead time, responding to market demand changes and meeting customer delivery dates has been heightened by the embarrassing success of foreign competitors.

There is hardly a scarcity of research on production scheduling. Much past research on production scheduling has focused on the relative performance of various dispatching rules in job shop systems (Moore and Wilson 1967). More recently, studies have recognized and considered the assembly production system as the setting for the analysis of scheduling rules (Biggs 1975; Maxwell and Mehra 1968). The underlying research objective for these studies has been to investigate the relative impact of different operating rules to guide the production researcher and practitioner in selecting the best scheduling policies.

Classical statistical tests of differences in the expected values of the distribution of various performance criteria have been employed to order by preference alternative scheduling policies.

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Research results indicate that the preference orderings of dispatching and scheduling rules are contingent not only on the performance criteria of concern but also on the type of production system investigated (Fryer 1973). Few of these studies have explicitly considered the utility function of the decision-maker in preference ordering scheduling policies. Preference ordering based on estimated expected values of performance measures is appropriate for utility maximization under the restrictive assumption of linear utility functions. Given the choice, one would always maximize utility by selecting the scheduling policy that results in the lowest expected cost and least risk. However, in many cases these results are inversely related. The relative performance of the shortest-processing-time dispatching rule in terms of job flow time illustrates this point. Lower expected costs (time being a surrogate for cost) may be associated with higher variance of expected cost. Thus, the existence of uncertainty of outcomes of various scheduling policies requires consideration of the decision-maker's utility function. Under conditions of risk aversion, where the utility function is concave, there is decreasing marginal utility of returns or cost reductions. Given an objective of utility maximization, one would expect unsound decisions to result when preference orderings are based on expected values and inappropriate utility functions.

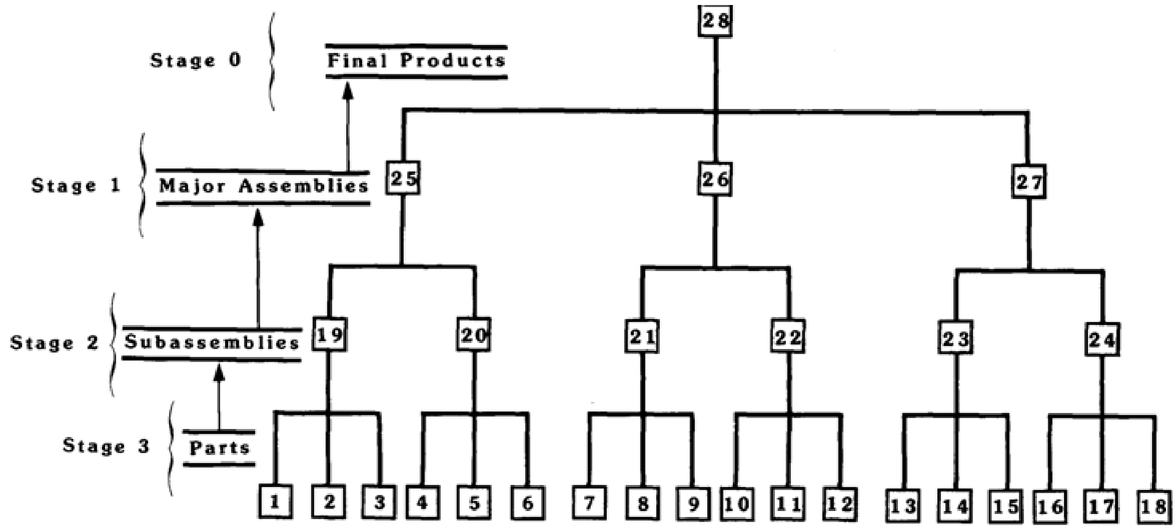
Preference orderings may be based on a more general efficiency analysis of the entire probability distribution of outcomes of scheduling policies without relying on specific assumptions about an individual's utility function. This approach, referred to as stochastic dominance (SD), provides the individual with ordering rules that have been shown to be theoretically superior to expected-value rules (Hadar and Russell 1969). The usefulness of the SD approach has been demonstrated in the areas of portfolio selection (Levy and Hanoch 1970, Porter et al. 1973), debt-issuance strategies (Brooks 1975), inventory control (Karlin 1960), and scheduling in the job shop environment (Weeks and Wingler 1979).

This study examines SD preference orderings of scheduling policies in an assembly-production setting. A production scheduling policy consists of a dispatching rule that identifies which job to process and a regeneration rule that updates the information used in the dispatching rule.

Previous research (Goodwin and Goodwin 1982) based on classical statistical analysis indicates that regeneration rules are relatively unimportant in terms of the expected values of performance measures investigated. However, these research results (Goodwin and Goodwin 1982) also indicate that regeneration rules do reduce the standard deviation of performance measures investigated and that there are significant interactions between the regeneration rules and dispatching rules. The impact and importance of these rules for risk-adverse decision-makers is inconclusive at best. It is the object of this study to clarify this question by investigating the SD preference orderings of scheduling policies in an assembly- production setting.

RESEARCH METHODOLOGY

A computer simulation model of a hypothetical assembly-production system was used to generate data for the scheduling policies investigated in this study. A detailed description of the model employed may be found in Goodwin (1976, pp. 26-70). The system consists of twenty-eight centres arranged in four major production stages as shown in the Figure. This structure emphasizes the features of a converging, tree-shaped assembly process. Each service centre provides a unique elemental task known as an operation and the time required to perform this task is the service time. Order interarrival times, service times and order sizes are stochastically determined. The interarrival times are exponentially distributed and order size is generated from a uniform distribution of integer values between 100 and 300. Service times are a linear function of order size. Since order



System structure.

size is random, service time is also a random variable. The expected service times are selected to yield a service centre utilization of approximately 90%. An unlimited labour supply is assumed and all labourers are equally efficient in operating any service centre.

Fifteen products are produced by the production system and each product is defined by the set of operations that is required to produce it. This 'set of operations' can be identified by determining a product's initial operations, i.e., those of Stage 3. After the initial operations of a product are completed, the product's components proceed through the system to the next highest stage along the fixed routeing. This process is repeated at each stage of the production system until the product is completed. Thus, the entire product structure follows from the unique set of initial operations. A variety of product structures is provided by varying the number of initial operations for the products and their distribution across the service centres at Stage 3 of the production system. When two or more components of a product converge at a service centre, the operations at this centre cannot begin until all converging components of the product are present.

The method used to define products in conjunction with the number and complexity of the products, creates significant commonality of parts, subassemblies and assemblies. Creating permanent imbalance in the system's work-load is a major problem of the commonality. However, product structure, order sizes and service times are selected to provide a balanced work-load across all service centres and at all the system's stages when each product is equally likely.

No orders are in the shop and all labourers and machines are idle at the start of each simulation run. Statistics for the first 50 000 time units are discarded to establish stochastic convergence. After the start-up period, each run is segmented into equal sequential time blocks to obtain multiple measures of performance. For each experiment in this study the same sequence of pseudo-random numbers is used to generated order and machine service characteristics. Therefore, the same set of orders is used in all cases. A particular order arrives at the same time and receives the same routeing and processing times for all cases. However, for each experimental condition different sets of orders are used across the different time blocks.

Orders are generated as a schedule of future demand or as a forecast. When an order is generated, a delivery date is assigned. A release date is calculated by subtracting from the order due date a time allowance equal to three times the total order processing time. Orders are released to the production system on their release dates and immediate shipment is assumed upon their completion.

A scheduling policy for released orders is comprised of two decisions : (1) dispatching rules to assign a priority to an order for processing from a queue at a work centre, and (2) regeneration rules to determine the frequency of updating priorities of orders in queue. The six dispatching rules used in this study are :

1. Shortest-processing time (SPT) where orders with the shortest work centre service times receive the highest priority.
2. Order due date (DD) where orders with the earliest due date receive the highest priority.
3. Operation due date (ODD) where operations with the earliest operation due date receive the highest priority. The operation due dates are determined by allocating the total production time allowance associated with an order to each individual operation in proportion to the service time at that stage of production.
4. Slack (SL) where orders with the least slack time (time remaining until the due date minus the service time remaining) receive the highest priority.
5. Operation slack (OSL) where operations with the least slack receive the highest priority.
6. Look ahead (LA) where priority of an operation is determined by the number of components waiting to be assembled with this component at the next sequential service centre. Operations with the most components waiting receive the highest priority. The shortest-processing time rule is used to break ties. (See Mellow (1966) for a general discussion of dispatching rules.)

Regeneration rules to determine frequency of priority updates include no regeneration (NR), periodic regeneration (PR) and continuous regeneration (CR). Periodic regeneration updates an order's priority no more than once during the time it spends in the system while continuous regeneration updates an order's priority every time an order is selected for service. With continuous regeneration the first three dispatching rules are static rules and the last three dispatching rules are dynamic in the sense that the order priority number changes over time. Continuous regeneration of dispatching rules has been assumed in virtually all previous research on job shop scheduling. With no regeneration, all the dispatching rules are static in the sense that order priority values remain unchanged over time.

The eighteen policies representing all possible combinations of the decision rule are defined in Table 1.

Several criteria are used to measure the system performance of these scheduling policies. Order flow time and tardiness are used as criteria of customer service. The mean number of parts waiting for converging parts of the same order (work-in-process waiting), total work-in-process, mean queuing time and waiting time per part are used as criteria of inventory costs.

RESEARCH DESIGN

The principal method of analysis of the results of the 18 experiments is second-degree stochastic dominance (SSD). (For a detailed explanation of SSD rules see Hadar and Russell (1969), Porter et al. (1973) and Quirk and Saposnik (1962)). SSD rules divide alternatives into efficient (undominated) and inefficient (dominated) sets for risk-adverse decision-makers by calculating the cumulative

Regeneration Rules	Dispatching rules					
	SPT	DD	ODD	SL	OSL	LA
NR	1	4	7	10	13	16
PR	2	5	8	11	14	17
CR	3	6	9	12	15	18

Table 1. Definition of scheduling policies.

differences between the cumulative probability distributions of alternatives. Estimation of these probability distributions is usually based on samples from populations. Previous research (Kroll and Levy 1980) indicates that the power of the SSD ordering rules is improved with larger numbers of observations (sample size).

As previously cited, most research on production scheduling has relied upon classical statistical analysis of expected values of results. Procedures have been recommended (Conway 1963, Fishman 1973) to determine adequate sample sizes and to block simulated data observations to compute correlated block means that may then be used as the basic observations.

Block means of the single response measures are computed as the basic data observations to be used in the expected value and SSD preference orderings of the 18 scheduling policies investigated. For each experiment (scheduling policy), a sample size of 30 observations of block means, each collected over a period of 50 000 time units, is used to estimate the parameters and probability distributions required to compare the scheduling policies. On the basis of previous research (Goodwin 1976), a block size of 50 000 time units was selected to provide independent (zero-correlated) block means. A sample size of 30 block observations was selected as a compromise between the substantial simulation costs of large sample sizes and the attendant increases in precision in estimating the true probability distribution resulting from large sample sizes.

EXPERIMENTAL RESULTS

The results in terms of performance means for the 18 experiments are shown in Table 2. Analysis of variance and multiple range tests were employed to iden-

Policies	Mean \VIP waiting	Mean WIP total	Mean tardi-ness	Mean flow time	Mean queuing time	Mean waiting time
1	15571	40203	5093	1682	689	1343
2	15571	40204	5091	1682	689	1343
3	15571	40208	5090	1682	689	1344
4	11054	35101	480	1630	759	1122

5	11054	35101	479	1630	759	1122
6	11057	35106	480	1630	759	1122
7	11009	35053	523	1685	784	1181
8	11009	35053	523	1685	784	1180
9	11012	35057	523	1686	784	1181
10	15755	40056	4149	1737	723	1383
11	12775	37020	1114	1654	740	1206
12	11037	35070	482	1641	763	1135
13	15852	40171	4105	1750	728	1397
14	12776	37029	1059	1673	748	1225
15	11024	35076	534	1695	789	1189
16	14907	39419	4822	1654	698	1272
17	13353	37853	3875	1656	722	1225
18	12606	37405	4273	1765	792	1286

Table 2. Experimental results.

	F-Level					
Factor	Mean WIP waiting	Mean WIP total	Mean tardi-ness	Mean flow time	Mean queuing time	Mean waiting time
Dispatching rule	16.08*	3.52*	243.57*	0.36	1.95	3.53*
Regeneration rule	10.86*	1.92	66.95*	0.20	1.07	1.96
Interaction of rules	2.55*	0.48	20.54*	0.27	0.27	0.79

* Significant beyond the 0.01 level

Table 3. Two-way analysis of variance of experimental results.

tify the best scheduling policies based on expected value ordering criteria. Analysis of variance was performed to test the homogeneity of the various dispatching rules and regeneration rules. As indicated by the analysis of variance statistics shown in Table 3, the null hypotheses that work-in-process waiting, work-in-process total, tardiness and waiting time for each of the dispatching rules are equal can be rejected. These results also indicate that the null hypothesis that work-in-process waiting and tardiness for each of the regeneration rules are equal can be rejected. Further, there are significant interaction effects for WIP waiting and tardiness.

Since these null hypotheses can be rejected, further analysis of the factor differences is necessary to order the significantly different policies by statistical preference. Duncan's Range (Winer 1962, p. 196) tests of the results shown in Table 2 were performed to test the null hypothesis of no significant differences among the scheduling policies. As indicated by the results shown in Table 4, the expected- value (E V) preference ordering of the scheduling policies depends on the performance measure under consideration. For the performance measures WIP total, flow time and queuing time, there are no significant differences among the 18 policies. Therefore, all the policies constitute the EV-efficient set for these performance measures. For WIP waiting, tardiness and waiting time, the EVefficient sets are comprised of various subsets of the 18 policies depending on the particular performance measure. More specifically, the EV-efficient sets for these three measures contain 12, 10 and 16 policies, respectively. Thus, EV preference ordering is not rigorous enough to isolate a small number of policies that yield better results with respect to any of the performance measures.

Based on overall performance, policies 4, 5, 6, 7 and 12 might be selected since they are in the EV-efficient set for all performance measures. As indicated by Table 1, policies 4, 5, and 6 are due date dispatching policies, policy 7 is the operation due date dispatching/no regeneration policy, and policy 12 is the slack dispatching/continuous regeneration policy.

A SSD preference ordering of the experimental results is shown in Table 5. The undominated policies constitute the efficient sets of policies from which any risk-averse individual will choose. The SSD-efficient sets will not usually include as many alternatives as EV-efficient sets. As indicated by the results shown in Table 5, the SSD-efficient sets are subsets of the EV-efficient sets. Assuming a
utility function characterized by diminishing marginal utility, the policies deleted from the EV-

Mean WIP waiting	Mean WIP total	Mean tardiness	Mean flow time	Mean queuing time	Mean waiting time
7	7	4	4	3	5
8	8	5	5	1	4
9	9	6	6	2	6
15	12	12	12	16	12
12	15	7	16	17	7
5	4	8	11	10	8
4	5	9	17	13	9
6	6	15	14	11	15
18	11	14	3	14	11
11	14	11	1	4	14
14	18	17	2	5	17
17	17	13	7	6	16
16	16	10	8	12	18
2	10	18	9	7	1
1	13	16	15	8	2
3	1	3	10	9	3
10	2	1	13	15	10
13	3	2	18	18	13

† Numbers in the body of the table are used to identify the 18 scheduling policies. Homogeneous subsets (at the 0·05 level of significance) of scheduling are indicated by connecting solid lines. Policies are ranked in descending order.

Table 4. Duncan's range tests of scheduling policies.†

efficient sets by the SSD rule must be inconsistent with maximizing expected utility. That is, for the performance measure 'order flow time', one might select any of the 18 policies using EV as the ordering rule (since there are no significant differences indicated) when policies 4, 6 and 11 are the best for the risk-averse utility maximizer. Therefore, SSD allows a substantially more sensitive selection of policies efficient for risk-averse managers.

Risk in this case is represented by the variance of the performance measure. Based on EV alone the policies are not significantly different in their effect on flow time. However, SSD is able to select more rigorously among the policies based on the simultaneous consideration of both mean and variance of the performance measures. Policies 4, 6 and 11 have an advantage over the other policies

Performance measure	Undominated scheduling policies
Mean WIP waiting	7, 15, 12, 5, 4
Mean WIP total	7, 8, 12, 18
Mean tardiness	4, 5, 7, 12, 8
Mean flow time	4, 6, 11
Mean queuing time	3, 1, 10, 13
Mean waiting time	4

t Numbers in the body of the table are used to identify the 18 scheduling policies.

Table 5. Second-degree stochastic dominance ordering of scheduling policies.t

based on the cost/risk relationship. The results presented in Table 5 clearly indicate that the more sensitive selection process provided by SSD holds for all the performance measures of this study.

Interestingly, the policies employing the shortest-processing-time dispatching rule are in the SSD-efficient set only for mean queuing time. A risk-averse pro duction scheduler, therefore, would never use this dispatching rule to optimize other performance measures. These results are consistent with previous findings (Weeks and Wingler 1979) and may indicate why risk-averse practitioners may not use the SPT dispatching rule. Even though it may result in low EV for numerous performance measures, this is often accompanied by relatively high variance (i.e. more risk).

As with the EV ordering, the best scheduling policies under SSD ordering depend on the performance measure considered. The SSD (and EV) results indicate that dispatching and regeneration rules do affect system performance and the selection of these rules to formulate a scheduling policy depends on the performance measure considered. That is, if the due date dispatching rule is selected to optimize order flow time then either the no regeneration or the continuous regeneration rule should be selected to form an efficient scheduling policy. However, if the slack dispatching rule is selected to optimize order flow time then the periodic regeneration rule is best.

CONCLUSION

Previous research in production scheduling literature has been concerned largely with investigating the effects of scheduling policies for job-shop systems based on expected value (EV) preference orderings. The purpose of this research was to investigate the effects of dispatching rules and regeneration rules in an assembly-production setting using stochastic dominance (SD) preference orderings. Second-degree stochastic dominance (SSD) rules are applied, along with EV rules, to order by preference the simulation results of a hypothetical multi-level assembly-production system.

SSD preference ordering provided a selection process of much greater sensitivity than EV ordering by considering another aspect of the performance measures, variability or risk. The number of policies contained in the efficient sets of policies for all performance measures was substantially reduced.

The results indicate that under SSD ordering, dispatching rules and regeneration rules affect system performance in a manner similar to EV ordering. The selection of these rules to formulate a scheduling policy cannot be made independently of the performance measure or independently of each other. The best dispatching rule depends on the performance measure considered and the regeneration rule selected.

For this study, however, the renowned shortest-processing-time dispatching rule was found to be an efficient rule under SSD ordering for only one performance measure, queuing time, and only when no regeneration or continuous regeneration is used. Similarly, with SSD ordering the relative performance of the other dispatching rules is contingent on the performance measure and the regeneration rule selected. These results suggest that periodic regeneration is not efficient for queuing or waiting time and that continuous regeneration is not efficient for waiting time. Further, the no regeneration/due date or the no regeneration/ slack policies are in the efficient set for all performance measures investigated.

This result is somewhat surprising since the previous research by Goodwin and Goodwin (1982) indicates that more frequent regeneration tends to reduce dispersion of performance measures. Based on this tendency, one might expect periodic and continuous regeneration policies to be favoured by SSD ordering. Evidently, the reduction in variance due to more frequent regeneration was not substantial enough to cause statistically significant improvement of risk-averse performance.

Since continuous and periodic regeneration require substantial implementation costs (computational time) relative to no generation, there seems to be little justification in using regeneration as long as the appropriate dispatching rule is selected.

The relative superior performance of the less complex dispatching rules has important implementation and control implications. The static due date and operation due date rules are efficient rules for all criteria except mean queuing time. The orders' priority values are easy to calculate, can be found before an order is released to production, and do not change over time for these rules. Beyond the simplicity of these rules, sequencing orders based on due dates is intuitively appealing.

The results of this research indicate that simple intuitive scheduling rules requiring minimum data processing are efficient for risk-averse managers. Before these findings can be generalized several areas for future research are readily apparent. There is a need to reevaluate the performance of dispatching rules in job-shop environments for risk-averse managers under varying conditions of regeneration. The impact of product structure, assembly system structure and labour constraints also need to be investigated. Since the effects of these variables have not been studied, it is only possible to speculate concerning their influence on system performance. However, it seems likely that both product and system structure would have significant influence on the results since they are crucial to the assembly process. For example, more complex product structures would create more complex assembly requirements, more commonality, and should have a substantial effect on measures like waiting time. Under circumstances such as these, regeneration may prove to be of considerably more value than it was in this study. In any event, the opportunities for additional research on scheduling in the assembly environment are numerous.

Cet article met par ordre de preference les diverses politiques de programmation faites des régles d'envoi et de regeneration dans un système de production de montage a plusieurs niveaux. On utilise des régles traditionnelles statistiques pour calculer la valeur prévue et la mise en ordre préférentiel par dominance stochastique du second degré afin d'identifier les politiques de programmation les plus efficaces pour des directeurs qui n'aiment pas les risques et qui utilisent diverses mesures de performance. Les résultats indiquent que la selection d'une régle de regeneration efficace depend de la selection d'une rregle d'envoi, et que ces régles doivant etre sélectionnèes conjointement si l'on veut développer des politiques efficaces de programmation. Dans le cadre de cette etude, on a pu trouver que des politiques de programmation qui sont attractives par intuition sont aussi efficaces.

Diese Abhandlung ordnet nach Präferenz verschiedene, Dispatch- and Regenerationsregeln umfassende Planungsverfahren für ein mehrstufiges Fließherstellungssystem. Unter Anwendung mehrerer Leistungsmaßstäbe werden traditionelle statistische Nennwertregeln und Regeln, die zweitgradige stochastische Dominanz nach Präferenz ordnen, zur Bestimmung der besten Planungsverfahren fur weniger risikofreudige Manager eingesetzt. Die Ergebnisse zeigen, daß die Wahl einer wirkungsvollen Regenerationsregel von der Wahl der Dispatchregel abhängig ist, und daß diese Regeln zusammen bestimmt werden müssen, wenn gute Planungsverfahren entwickelt werden sollen. Für diese Studie stellten sich unmittelbar ansprechende Planungsverfahren als wirkungsvoll heraus.

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