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Abstract

We investigate an integrated manufacturing system made up of both FMS as well as conventional machines. We develop both shop selection heuristics and rescheduling scenarios in the article. We report on the benefits of implementing a rescheduling strategy using a simulation based expert system that uses the heuristics developed.

Motivation

Modern manufacturing facilities consist of conventional manufacturing systems like numerical control (NC), computer numerical control (CNC), and direct numerical control (DNC) machines, grouped together as work centers, in addition to Flexible Manufacturing Systems (FMS). An FMS involves a large capital investment, but provides a high degree of flexibility and a better utilization of resources. Often, these shops have the allocation and processing of jobs in an integrated, conventional plus FMS, environment as a decision problem. The main problem here is to identify which product or products and in what quantities should be produced on the FMS, or conventional manufacturing system or both.

There is very little research in the area of Integrated Manufacturing Systems (Conventional Manufacturing Systems and Flexible Manufacturing Systems working in tandem). Avonts, 1988 demonstrated how a simple linear programming model on a microcomputer could be used as a valuable decision making instrument for an Integrated Manufacturing Shop. He also demonstrated how the linear programming model can be used as a device to choose strategies to be to be tested in a detailed simulation of the system. Stylianides, 1995 developed a simulation model of an Integrated Manufacturing System that predicted the economic impact of the FMS on the production operations, throughput rate, and system utilization.

Decreasing product life cycles and economies of scale demand a better and more scientific approach to this decision-making scenario. Today=s methods for automatic production control show several deficiencies. Random disruptions in particular are disregarded, leading to frequent re-scheduling. A recent survey of several manufacturing shops showed that about a third of all orders could not be finished as planned due to various constraints. There has been a growing interest in developing expert shop floor control systems (ES), that use simulation technology to extract the potential of integrating the new technologies into the existing manufacturing environment. The high investment cost of the FMS justifies the use of computer simulation support in the decision making process. There has been a lot of recent research in the area of developing expert simulation systems for FMS (Gupta et al. - 1989 and Sabuncuoglu and Hommertzeim - 1988). The objective of this paper is to review the recent developments in simulation and to discuss the role of expert simulation systems (ESS) in Integrated Manufacturing environments.

In this work we have developed a generic rule based Expert System (ES) which directs the simulation. Using the ES we have addressed the issues of dynamic scheduling and the effect of re-scheduling in a dynamic shop environment. The shop that has been researched is an integrated shop that has two components: a FMS shop and a conventional shop.

Literature Survey

Because of the nature of the structure of the Integrated Manufacturing Shop, more complex scheduling, planning and control systems are required than for conventional manufacturing shops. A number of analytical approaches have been proposed for control of flexible manufacturing shops. Buzacott and Yao, 1986 emphasized that a FMS based shop is extremely complex, and no single analytical model can be used to describe its behavior fully. Any real time production scheduling and control system should be able to respond to dynamic changes in the system status and provide a revised schedule when needed. The use of artificial intelligence (AI) techniques, to control such systems have been proposed. There is little research in the area of expert systems dedicated to dynamic control of FMS shops.

Recently, there has been a huge contribution from management and organization theory (decision making), statistics, mathematics, management science (heuristic programming, cost effectiveness), and management information systems to the area of Expert Systems (Morton and Pentico, 1993). In today's world ES are of great interest to organizations because of their ability to enhance productivity and to augment work forces in many special areas where human experts are increasingly difficult to find and retain. Typically, human experts possess characteristics that allow them to solve problems quickly and fairly accurately, explain their actions, and communicate with other experts. Human experts learn from experience. They also use tools, such as rules of thumb, mathematical models, and detailed simulations to support their decisions. An expert system can perform all these functions, in addition to combining experiences from a variety of fields..

Growing attention has been paid to finding solutions for most of the problems related to manufacturing systems using simulation models. Several real-time scheduling systems have been proposed for FMS with simulation models to support the ES in dealing with complex decision-making problems (Ben - Arieh: 1987). In the last few years, computer based simulation models have been used to represent a wide area of technical and organizational systems (Belz and Mertens 1996). Belz and Mertens show the possibilities of combining expert systems with simulation to solve problems in the area of scheduling and re-scheduling. The ES acts as an intelligent front end, which interfaces the simulation with the user. The system facilitated the use of simulation even by novices because they only have to deal with the ES.

Sabuncuoglu and Hommertzheim, 1989 use an expert simulation system, ESS approach to develop a framework for FMS scheduling. They used this approach in an FMS to select the appropriate scheduling rule based on shop objectives. The rule based scheme had rules built in the form of IF..THEN statements that reached conclusions based on shop conditions.

Gupta et al, 1989 developed an expert scheduling system for a flexible manufacturing cell. A variety of scheduling criteria were experimented, based on job completion times, in-process jobs, due-date, cost, and a variety of dispatch rules. They suggested the use of incorporating results from active experimentation in a simulation model with existing expert knowledge, as a method of developing an improved knowledge base for the ES. SIMAN was used to develop the expert scheduling system (ESS).

Garg and Wang, 1989 developed an expert simulation system (ESS) to dynamically schedule in a FMS environment. The ESS scheduled the system based on loads or the status, that continuously changed, necessitating a review of the scheduling strategy of the system.

Sharit and Salvendy, 1987 developed a real-time interactive model of a flexible manufacturing system, with emphasis on the system structure and models interactive component. An attempt was made to illustrate how the model could be used to extract knowledge concerning human strategies at control activities like scheduling, re-scheduling, routing and re-routing. This knowledge is extremely essential for the development of expert systems, ES that would control the FMS shop.

We have reviewed relevant expert scheduling simulation systems reported in the literature. We have identified a number of ESS approaches used by researchers. There is little or no research in the area of developing expert systems (ES) for integrated manufacturing environments. Ludwig, 1988 developed a linear programming model that permitted easy evaluation of different objective functions and decision alternatives. Stylianides, 1994 developed a simulation model that predicted the economic impact of FMS on production operations, in an Integrated Manufacturing Environment. The literature review points to the need for investigating expert simulation / scheduling systems (ESS)in Integrated Manufacturing Environments. Scheduling, re-scheduling, job routing, accept / reject decisions, due-date analysis, and maximizing shop objectives are some of the possible operations that can be carried out by the ESS.

Integrated Shop Design

The integrated shop is made up of a conventional shop and an FMS. The conventional shop modeled consists of five machines. The FMS that is modeled has from one to three machines. The design of the Integrated Shop is generic, such that it can model a shop with completely overlapping operations or partly overlapping and partly disjoint operations. The model has been set up to test for different shop arrival rates with different settings of the FMS. The whole shop has been simulated using discrete event simulation.

There are five different job types that can be processed by the Integrated Shop. Job type 3 and 4 are high priority high weight jobs. Job type 4 has the highest weight followed by job type 3. Both the above job types can only be processed in the FMS part of the shop. Job type 1, 2 and 5 can be partially processed in the FMS. Job types 1 and 2 are Afrontends@ while Job type 5 is a Aback-end@. AFront-end@ here refers to the option of processing the first three operation in either of the two shops. ABack-end@ refers to the option of processing the last three operations in either of the two shops. Weights can be assigned to job types 1, 2, and 5. Job types 3 and 4 are high weight jobs and have fixed weights. The five job types which have different priorities, weights, loading patterns, processing times and earnings were selected to test the Integrated Shop for product types, ability to meet due dates, throughput rate, economic impact of the FMS on production operations, and the performance of the rule based expert system. The front-end and back-end approach is an attempt to load both the FMS and the conventional manufacturing shop equally. The Integrated shop design and the number of job types helped test the ability of the Expert System to extract the flexibility of the Integrated Shop, available through the FMS.

The simulation of the shop starts with an empty shop. This is not the normal state of affairs. Jobs enter the shop at regular intervals of time. Therefore the simulation will often have a warm-up period. At the end of this period the system is declared warmed-up and data collection begins. The measuring period is from the end of the warm-up until the end of the simulation run. The warm-up period is parameterized in the simulation model.

It is assumed that the shop will receive a random number of jobs during the interval of the simulation. The job arrival rates follow a Poisson distribution so as to model a number of random events occurring in any interval of time. Set up times on the FMS machines are extremely small. Hence the set up times have been assumed to be a part of the processing times. Set up times on the machines in the conventional shop have been modeled to be a constant and job type dependent. The processing times range between one and three times the set up times. Only the first job in a sequence of jobs of the same type on the same machine incurs the set up time.

The processing times in both the shops have been assumed to be fluctuating around a mean. The times are sequence independent and are assumed to be exponentially distributed. Machines 3, 4, and 5 in the conventional shop perform operations 1, 2, and 3 on Job types 1, and 2, and operations 3, 4, and 5 on Job type 5. These operations can also be carried out on FMS machines. All operations on FMS machines are carried out in one setting. Operations on Machine 3, Machine 4 and Machine 5 for the job types 1, 2 and 5 are performed by a single FMS machine. The remaining processing is carried out in the conventional shop as the facilities for the same are not available in the FMS shop. Job types 3 and 4 have only one operation and can only be processed in the FMS shop.

Transportation time is affected by the availability of an AGV. An exponential distribution has been chosen for both transportation times. As can be seen from Figure 1 the FMS has only one queue. An AGV is provided which allows for dynamic scheduling of the jobs in the queue. As travel from any part of the queue to any one of the FMS machines is small, travel time within the FMS has been assumed to be a part of processing time. Expected departure time assignment is done using the Total-Work rule for all jobs. The formula used is stated below:

$$D_j = A_j + \alpha \times P_j$$

A_j = Time in simulation clock when the job j entered the shop
D_j = Due-date of job j
α = Due-date factor assigned to job j
P_j = Processing time of job j

The experimental parameter α can take a value anywhere between 2 and 7. As part of this paper due-date allocation has been made at a static and a dynamic level. At a static level, α has been set for a minimum level of tardy jobs. At a dynamic level α has been set using shop conditions, characteristics, customer expectations and profit factor. The integrated shop has three levels of congestion, namely low, medium and high. The value of α increases with the increasing congestion levels, as part of the dynamic due-date model.

Objective Measures

The objective measures to be used as part of the expert system are minimum average flow-time, minimum average tardiness and maximum profit.

Expert Simulation System Design

Siman V was used as the simulation-modeling tool. All experiments were carried out on a desktop PC. Figure 1 gives a block diagram of the model researched. Figure 2 specifies the framework used in the rule based expert system that directs the simulation model. Jobs in Siman are called entities. Every entity is assigned a set of job attributes: namely due-date, time-in, weight and machine sequence. Before accepting the job the ES checks the customer expectation, assigns a customer factor, checks the system due-date factor, and makes a decision to accept or reject the job. Upon completion, the job leaves the system updating statistics. The rule based scheduling shell routes and dispatches jobs based on objective measures and system characteristics. The user interactively selects these. The system uses simple IF-THEN-ELSE rules to schedule jobs.

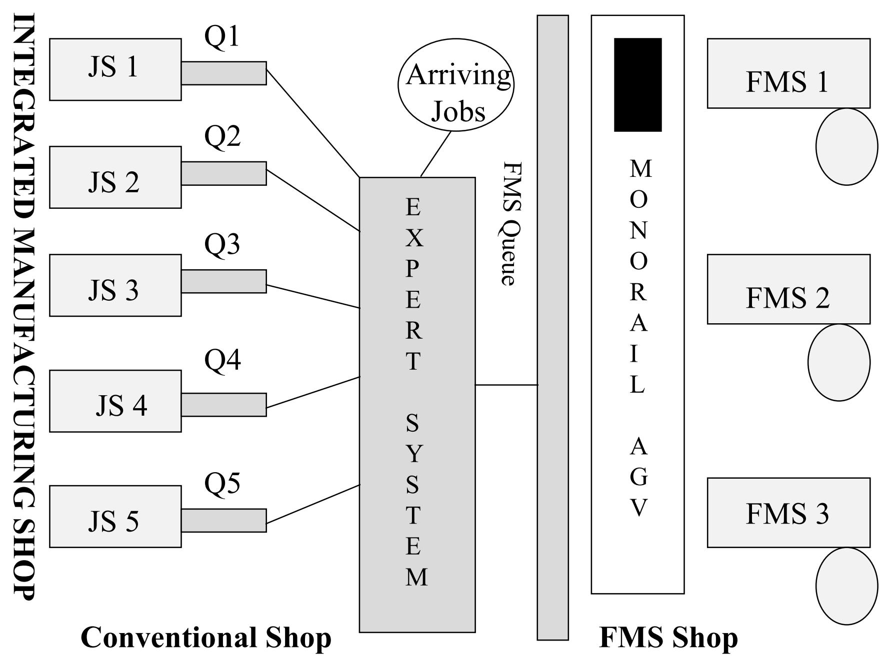

Figure 1. Integrated Manufacturing Shop Model

Re-scheduling

A scheduling system makes decisions about matching activities and resources in order to finish jobs or orders in a timely fashion, simultaneously maximizing throughput and earnings, and minimizing operating costs. There are three types of scheduling: a) Sequencing based scheduling; b) Scheduling based on Dispatch rules; c) Routing based scheduling. In a dynamic environment the task of scheduling is a difficult one. The continuously changing conditions in a system calls for a dynamically changing scheduling system.

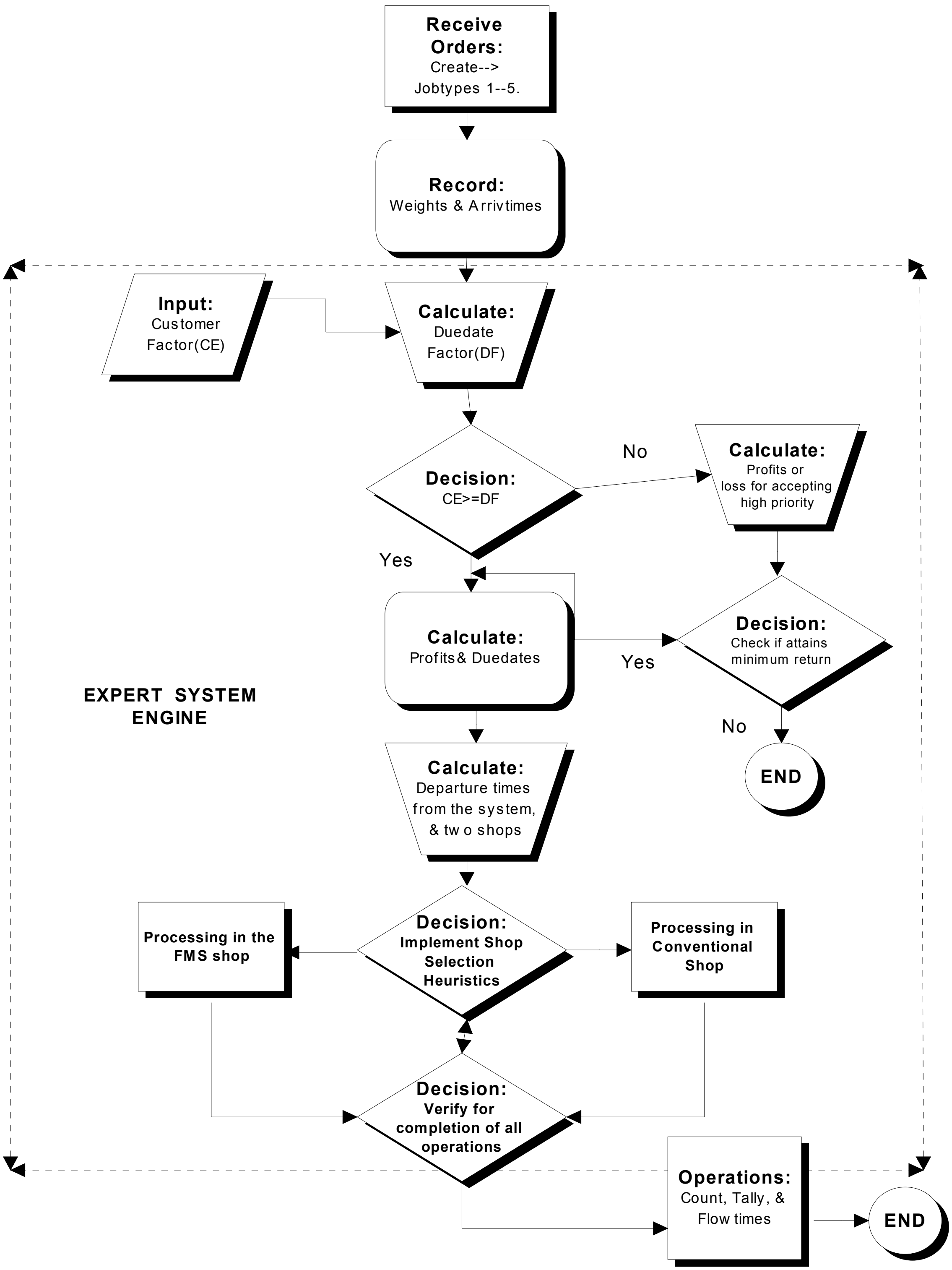

Figure 2. Block Diagram of Expert System

Re-scheduling can be defined as a goal driven strategy that attempts to involve shop characteristics, shop objectives and dynamic shop status information to perform effective sequencing, dispatching, or both.

Muhlemann et al, 1982 investigated a re-scheduling strategy for a fifteen machine job shop. Frequent scheduling produced significant improvements in the shop performance. Belz and Mertens, 1996 developed an expert system called ASimulex@, capable of dynamic scheduling and re-scheduling. The results revealed the robustness of the scheduling approach. Garg and Wang, 1989 demonstrated the effectiveness of a re-scheduling approach in a FMS environment. Periodic and turnpike re-scheduling with either job routing or dispatching rules were some of the approaches used in the literature reviewed. All of the above research was either in area of conventional manufacturing systems or FMS. There is little or no research in the area of Integrated Manufacturing Systems (conventional systems plus FMS). As part of this research, we have combined some of the approaches available through the literature review and tested the same with different re-scheduling triggering criteria in an Integrated Manufacturing Environment.

Re-scheduling is the process of changing sequencing and dispatching rules, in a continuously (dynamic) changing shop based on shop conditions and objectives. Re-scheduling could be triggered by either a change in shop conditions or based on future shop congestion to meet the objective measures for the shop. Two approaches could be used to trigger the re-scheduling process: a) Change in shop conditions; b) Periodic Re-scheduling. As part of this work, we have used change in shop conditions as a trigger for the re-scheduling process. The challenging task is to identify a shop parameter that could be used as an effective tool in identifying and implementing a re-scheduling process. We evaluated a) Flow time; b) Number of Tardy Jobs; c) Shop Earnings, as possible tools in the identifying a change in shop conditions.

Shop Selection Heuristics and Dispatching Rules in Re-scheduling

Table 1. Shop Selection Heuristics

Heuristic 1	Critical Factor Heuristic
Heuristic 2	Average Due-date Heuristic
Heuristic 3	Waiting Time Heuristic
Heuristic 4	Expected Flow time Heuristic
Heuristic 5	Job Due-date / Expected Departure Time Heuristic

The shop selection heuristics proposed here perform differently under different conditions. For each of the heuristics, shop performance varies with the value of a constant called the AFactor@. The factor is a decision variable. It identifies a limiting value beyond which the new job is either sent to the conventional shop or the FMS shop. The five factors are, Critical Factor, Utilization Factor, Waiting Factor, Flow-time Factor and Due-date / Departure Factor. One hundred and fifty simulations were performed, with different values of the factor.

Results

The performance of the shop selection heuristics and dispatching rules has been listed in Table 2. The decision to re-schedule is made when the performance of the chosen shop parameter deteriorates. An analysis of Table 2 reveals that re-scheduling performs as efficiently or better than SPT (with each of the shop selection heuristics). The re-scheduling results are sensitive to the value of Aη@, Aδ@ and Aε@, the rescheduling markers that were experimentally set in the simulation. A lower value of the decision variable implies frequent re-schedules and vice-versa.

From Table 2 it can be seen that the re-scheduling process yields better results when flow time is chosen as a shop parameter to trigger the re-scheduling process. The number of tardy jobs and earnings percentage are relative to the due-date assigned to the job. Hence re-scheduling with the number of tardy jobs or earnings ratio does not indicate the true present state of the shop. However re-scheduling with a direct alteration to the due-date assignment process could yield better results. A paired difference t-test based on 10 replications reveals that there is a statistical difference between using SPT and some of the shop selection heuristics when used as part of the re-scheduling based strategy. Table 3 provides details about the t-test.

Conclusions

The shop selection heuristics developed as part of this work provide a useful allocation tool to dynamically allocate jobs / orders between the two shops in an integrated environment with both FMS and conventional job shops. This is because the selection heuristics use dynamic job and shop status, and shop characteristics in the allocation process. The re-scheduling heuristic developed and experimented with as part of this paper provides an effective tool to improve the shop performance. The results indicate a clear advantage in re-scheduling based on periodic evaluation of system performance. The results from the re-scheduling based strategy indicate that there is a clear advantage to using flow time as a re-scheduling trigger. Extensions of this work can clearly be made to environments with other types of integrated shops and having other criteria for evaluating shop performance.

Table 2. Performance of Re-Scheduling Module

		Tardy	Actual Earnings
	Flowtime	**Jobs**	**Millions**
Shop Parameter-Flowtime Dispatching Rule: SPT Value of "n" : 1.10			
Critical Factor Heuristic	117.13	441	24.80
Average Due-date Heuristic	114.36	528	23.76
Waiting Time Heuristic	117.24	658	22.56
Expected Flow time Heuristic	111.66	524	23.66
Job Due-date/Expected Flow time Heuristic	129.11	643	23.71
Shop Parameter Tardy Jobs Dispatching Rule: SPT Value of "n" : 1.00			
Critical Factor Heuristic	134.73	622	22.48
Average Due-date Heuristic	111.04	552	23.52
Waiting Time Heuristic	123.04	699	22.59
Expected Flow time Heuristic	118.81	596	23.81
Job Due-date/Expected Flow time Heuristic	114.95	580	23.85
Shop Parameter – Actual Earnings Dispatching Rule: SPT Value of "n" : 1.00			
Critical Factor Heuristic	161.05	797	21.29
Average Due-date Heuristic	145.86	1234	22.36
Waiting Time Heuristic	114.80	1183	23.48
Expected Flow time Heuristic	113.48	539	24.07
Job Due-date/Expected Flow time Heuristic	168.57	665	21.00
No Re-Scheduling Dispatching Rule: STP			
Critical Factor Heuristic	155.69	894	21.22
Average Due-date Heuristic	122.88	677	23.25
Waiting Time Heuristic	110.51	524	23.93
Expected Flow time Heuristic	118.44	537	24.15
Job Due-date/Expected Flow time Heuristic	152.99	853	21.13

Table 3. Paired t-Difference Test at 95% Confidence Interval

Comparison	p -Value Using Re-Scheduling Criteria		
	Flow-Time	Tardy Jobs	Actual Earnings
Critical Factor Heuristic and SPT VS. Re-scheduling Strategy	.8467	0.0001	.1082
Average Due-date Heuristic and SPT VS. Re-scheduling Strategy	.0110	.6522	.3389
Waiting Time Heuristic and SPT VS. Re-scheduling Strategy	.2995	0.0061	.3487
Expected Flow-Time Heuristic and SPT VS. Re-scheduling Strategy	.3903	0.0083	.3997
Due-date / Departure Heuristic and SPT VS. Re-scheduling Strategy	.0416	.0513	.4153

The underlined statistics are significant at the 95% level of confidence.

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