SIMULATION AND COMPARISON ANALYSIS OF DUE DATE ASSIGNMENT METHODS USING SCHEDULING RULES IN A JOB SHOP PRODUCTION SYSTEM

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ABSTRACT

This paper presents a simulation and comparison analysis conducted to investigate the due-date assignment methods through various scheduling rules. The due date assignment methods investigated are flow time due date (FTDD) and total work content (TWK) method. Three scheduling rules are integrated in the simulation for scheduling of jobs on machines. The performance of the study is evaluated based on the configuration system of Hibret manufacturing and machine building Industry, subsidiary company of Metals and Engineering Corporation were thoroughly considered. The performance of the system is evaluated based on maximum tardiness, number of tardy jobs and total weighted tardiness. Simulation experiments are carried in different scenarios through combining due-date assignment methods and scheduling rules. A two factor Analysis of variance of the experiment result is performed to identify the effect of due-date assignment methods and scheduling rules on the performance of the job shop system. The least significant difference (LSD) method was used for performing comparisons in order to determine which means differ from the other. The finding of the study reveals that FTDD methods gives less mean value compared to TWK when evaluated by the three scheduling rules.

KEYWORDS

Due dates assignment, Scheduling rules, Tardiness, Flow time due date, Total work content

1. INTRODUCTION

In a typical job-shop, potential customers dynamically arrive with a request for work. The shop management and the customer negotiate with respect to the volume, mix, and specification of products desired, the promised due-date, and the price [1]. Negotiating and meeting due dates is one of the most important and challenging problems in production management.

The performance system of a Job shop scheduling is optimized with scheduling and sequencing jobs in any production system. This measure includes job finish times and estimation of due dates that have major impact on the current global competition. However, the ability to meet due dates is dependent not only on the performance measures but also the variation relationships between job dispatching procedures and the reasonableness of the due dates. The reasonableness of the promised due dates can be seen in to two different ways. One is delivery reliability which is the ability consistently meet promised delivery dates; second is the ability to deliver orders to customer with shortest lead times [2].

In today's production thinking, manufacturing companies are striving to reduce the risk of failure in meeting due-dates by controlling the performance. Failing to meet due dates results inventory carrying cost when early job completion exists and penalties for a tardy job completion. The due date assignment methods consist of making an estimate of flow times for a certain job depending on the shop utilization ratio and setting a due date on the basis of the estimation with some performance criteria.

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The present paper focus on a simulation and comparison of the interaction between due-date assignment methods and scheduling rules in a job shop production system. Two due-date assignment methods and three scheduling rules are considered for the investigation. The performance of the case industry job shop system is evaluated using tardiness as a parameter aided with statistical analysis.

The rest of the paper is organized as follow: Section 2 deals with the problem definition used in the present study. In section 3 the research methodology is presented. Section 4 contains the literature about shop floor configuration. In section 5 the development of simulation analysis. This section also describes the simulation experiments. Result and discussion are provided in section 6. Finally in section 7 a conclusion is given for the study.

2. PROBLEM STATEMENT

The Metal and Engineering Corporation (METEC) is established by the Federal Republic of Ethiopia (FDRE) under council of minster regulation No 183/2010 in June 2010 [3]. METEC is comprised of more than 15 semi-autonomous and integrated manufacturing companies that are operating in different sectors. Hibret manufacturing and machine building industry is one of the manufacturing company under METEC. HMMBI has five factories: machine building factory, conventional manufacturing factory, precision machinery factory and material treatment and engineering factory. HMMBI has a challenge to meet duet of its internal and external customers. Through a structured interview and questionnaire conducted with production department heads, the basic procedures and practices in the HMMBI are thoroughly examined. Based on the analysis the critical problem for the late deliveries in the case industry has been identified. By taking the actual shop floor data of the case company, the performance of the delivery system is evaluated. Simulation and comparison analysis are carried in different scenarios through combining due-date assignment methods and scheduling rules. Finally the performance of the job shop system is evaluated tardiness parameters including maximum tardiness, number of tardy jobs and total weighted tardiness.

3. RESEARCH METHODOLOGY

The aim of this research is to compare and select one of the due-date assignment methods for different scheduling rules based on performance measure parameters. A case industry HMMBI conventional manufacturing section having a job shop system is considered for investigation in the present study. The system consists of four work stations namely lathe, milling, heat treatment and surface finish stations in each station different machine performing different operation. Two methods from the literature are used for setting due dates of jobs; flow time due date (FTDD) and total work content (TWK) and three scheduling rules are used for the scheduling of jobs. These rules include shortest processing time (SPT), earliest due date (EDD) and critical ratio (CR). The performance measures considered for analysis are maximum tardiness, total tardiness and number of late jobs. Simulation experiments have been conducted and subjected to a statistical analysis through different scenarios that arise out of the combination of due-date setting methods and scheduling rules.

4. JOB SHOP SYSTEM CONFIGURATION

An actual case company HMMBI conventional manufacturing job shop configuration has been used for investigating the present study. The configuration consists four station having different machines and perform different operation.

4.1. Current Scenario of the Shop Floor

The present study focus on scheduling and sequencing a job shop system having the following characteristics:

- There are a more than one machines in the four workstations.
- Each machine in each workstation can perform only one operation at a time.
- An operation of a job can be loaded in any of machine in the workstation according to the process plan of the job order.
- Each machine is continuously available and no machine is idle.

4.2. Job and Machine Data

According to the process plan of the production station each job order consists of a set of operations to be performed on the different station in the shop. The routing of a job through the machines is extracted from the process plan document and presented below in tabular form. The process plan conveys the stations with respect to the machines, the processing time of each operations of a job. In generating the job data, the case company standard operation plans have been taken in to consideration.

Table 1: Job and Machine data

<table>
<tr><th colspan="6">Number of Machines in Each station</th><th></th></tr>
<tr><th>Station Name</th><th>Lathe Station(LS)</th><th>Milling Station(MS)</th><th>Heat treatment station(HTS)</th><th>Surface finish station(SFS)</th><th>Total machines</th><th></th></tr>
<tr><td>Number of machines</td><td>30</td><td>15</td><td>3</td><td>20</td><td>68</td><td></td></tr>
<tr><th colspan="7">Job routines and processing time</th></tr>
<tr><th rowspan="2">Job. No</th><th rowspan="2">Job Description</th><th colspan="4">Routines</th><th></th></tr>
<tr><th>LS</th><th>MS</th><th>HTS</th><th>SFS</th><th>Pr. Time</th></tr>
<tr><td>1</td><td>Coupling Male part</td><td>3</td><td>4</td><td>3</td><td>7</td><td>17</td></tr>
<tr><td>2</td><td>Worm gear small</td><td>3</td><td>6</td><td>-</td><td>-</td><td>9</td></tr>
<tr><td>3</td><td>Worm gear driven shaft small</td><td>4</td><td>-</td><td>-</td><td>-</td><td>4</td></tr>
<tr><td>4</td><td>Support for mixture shaft</td><td>4</td><td>-</td><td>3</td><td>4</td><td>11</td></tr>
<tr><td>5</td><td>Condorm (c-blade)</td><td>-</td><td>5</td><td>3</td><td>4</td><td>12</td></tr>
<tr><td>6</td><td>Seal Sleeve</td><td>3</td><td>1</td><td>-</td><td>5</td><td>9</td></tr>
<tr><th colspan="7">Average Setup times of machines</th></tr>
<tr><td>1</td><td>Lathe machine</td><td>0.85</td><td colspan="4" rowspan="4"></td></tr>
<tr><td>2</td><td>Milling Machine</td><td>2.25</td></tr>
<tr><td>3</td><td>Grinding Machine</td><td>1.1</td></tr>
<tr><td>4</td><td>Heat treatment(Furnace)</td><td>3.4</td></tr>
</table>

4.3. Due-Date Assignment

When a job arrives at shop at the processing, its due date needs to be assigned. Currently the case industry assigns due dates for customers according to the shop load utilization but due dates scientifically can be assigned. Among the different due date assignments methods, for this study two different due date assignment methods are investigated and compared through statistical analysis. Both the selected methods belong to the category of internally set due date's i.e. endogenous due-date methods. These methods are discussed as follow. In addition to the following notations used:

Notations:

DDi = Due date for order I,
ATi = Arrival time for order I.
TWKPi = Total run time for order I.
Ki = Planning factor used for all jobs
TWKSUi = Average setup time for all jobs.
NOPi = Number of operations for order I
Ft= average flow time of a job
Ki = tightness level at the time
λ = average job arrival rate
Up = mean operation processing time
Ug = average number of operation per job
Pij = processing time of operation j of job i
Wij = waiting time of operation j of job i
gi = number of operations in job
E(F) = standard deviation
σ = mean value
Ri = arrival date of the job
Z = shop load ratio
P = shop utilization
m = number of machine

4.3.1 Flow Time due Date Assignment (FTDD) Method

The time a job spends in the shop, from the order release to completion is called its flow time. The mean job flow time is the basic measure of a shop's performance at turning around orders, and it is therefore often used as an indicator of success quickly to customers [8]. Due to the complexity of job shop structure, flow times elements become uncertain which makes prediction of due dates more difficult. However accurate prediction of flow time in job shop is one of the most important factors for efficiency of scheduling. If flow time predictions can be significantly improved through use of shop utilization information errors between actual competitions times and promised delivery dates can be reduced.

- The mean and the standard deviation of job:

Flow-time F is the difference between the arrival time of job J, in the shop and the completion time of the last. Operation of J" F, can be derived from the sum of the total processing times and the total waiting times of J, in the shop as follows:

$$Fi = \sum_{j=1}^{gi} pij + \sum_{j=1}^{gi} Wij$$

The waiting time, W'j, can be expressed as:

$$\sum_{k=1}^{tij-1} p^j\,[k]_j + y_{ij}$$

The standard deviation and the mean will result in:-

$$E(F) = \sum_{j=1}^{gi} Pij + gi\left\{\left(\frac{yUgUy}{m(1-p)} - 1\right)U_p + Uy\ \right\}$$

$$\sigma = \sqrt{gi\left\{\left(\frac{\lambda UgUy}{m(1-p)} - 1\right)\right\}\sigma p^2 + \sigma y^2}$$

The due date formula is (Di) = Ril +E(F)+Z($\sqrt{\sigma^2}$) , Where Ri is arrival date of job and E(f) and σ are found from the above formula and Z is shop load ratio, considering the shop utilization [4].

$$P = \frac{\lambda \text{UpUg}}{m}$$

4.3.2. Total Work Content (TWK) Assignment Method

This model follows the job dependent assignment procedure. The assigned due dates are proportional to the total estimated processing time of a job. The TWK methodology has been employed by numerous researchers; it is based on the average setup time of a job, total estimated processing time and planning factor allowance that accounts for delays.

In this method the due date of each job is set equal to the sum of job arrival time and a multiple (allowance factor) of the total processing time. For each new order I, the due date can be calculated as follows: [4]

$$DDi = ATi + (TWKPi * Ki) + (TWKSUi * Ki * NOP)$$

Dynamic total work content (DTWK) method it is a modification of the TWK method, where in the due-date planning factor K, is determined using the information about the Status of the job shop at the time a job arrives at the shop [5].The application of Little's law (1961) for a job shop in the steady state operation results in the following relationship, If Ns denote the number of jobs in the system, λ denote the average job arrival rate and F denote the job flow time, then Little's law for a shop in steady state can be expressed by If it is assumed that the shop load is relatively steady for a short period of time, then any given time t, it can be approximated the average flow time of a job Ft, in the shop with Ns number of jobs in this period as:

$$Ft = \frac{Nst}{\lambda}$$

The dynamic allowance factor for a job newly arrived at time t would be determined by the current average flow time. Denoting the mean operation processing time and average number of operations per job by Up and Ug, respectively, we see Up Ug that is the average total job processing time. Let KI denote the real tightness level at the time t when a new job arrives,

Then KI = $\frac{Ft}{\text{Up Ug}}$

5. SCHEDULING RULES

Scheduling in job shop is an important aspect of shop floor management system, which has significant impact on the performance of the shop-floor. The decision as to which job is to be loaded on a machine, when the machine becomes free is normally made with dispatching rules [6].Scheduling rules can be classified in a number of ways, one such classification follows process-time based rules, and due-date based rules and combination rules. In this simulation study of job shop system all three ways used, the shortest process-time (SPT) is an example of process time based rule. This rule has been found to minimize the mean flow time and a good performance with respect to the mean tardiness. The due-date based rule schedule the rule based on their due-date information, an example is earliest due date (EDD) mostly used for light load conditions. A combination rule makes use of both process-time and due-date information, example is critical ratio (CR).

6. SCHEDULING RULES

The simulation analysis is developed for evaluating the performance of the two due date assignment methods using scheduling rules. The entities in the job shop system are jobs and machines. Simulation is done using Lekin scheduler. Based on the simulation results a comparison analysis is done using ANOVA (SPSS statistics 20).

6.1. Structure of Simulation and Comparison Analysis

In this paper the simulation and comparison analysis are structured in modular way consisting three modules, each of which performing a specific role.

Table 2 : Simulation and comparison modules

Factors	Levels
Due–date assignment module	Flow time due date(FTDD)
	Total work content(TWK)
Scheduling module	Shortest processing time(SPT)
	Earliest due date(EDD)
	Critical ratio(CR)
Result module	Tardy jobs Average Tardiness Mean flow time

- **Due-Date assignment module:** This module generates the final due date of the jobs that arrive at the system. The due date method used are the flow time due date (FTDD) and total work content (TWK). The number of operations, number of machines required for operation and processing time of jobs were used from the actual data of the case company to finally incorporate the due date with the two methods.

- **Scheduling module:** According to the process plan this module contains subroutines to deal with the scheduling of jobs on machines using various scheduling rules. For making decision, a scheduling rule is used to assign to each of the waiting jobs, a scheduling rule. As aforementioned on the above sections the study used three scheduling rules from literature. These are shortest processing time (SPT), earliest due date (EDD) and critical ratio (CR).

- **Result module:** This module presents the output of the simulation analysis that aids the comparison analysis of the two assignment methods through performance measures such as mean flow time, tardy jobs and average tardiness.

Notations:

Cmax-Maximum Span

Tmax- Maximum Tardiness

∑Tj- Total Tardiness

∑WjCj- Total weighted tardiness

∑Uj- No of late jobs

7. RESULT AND DISCUSSION

By analysing the two due date assignment through three scheduling rules, the job due date and simulation results for both methods is presented below:

Table 3: Job due date with FTDD and TWK

Job number	1	2	3	4	5	6
Due date using FTDD	17	12	8	13	14	11
Due date using TWK	6	1	1	21	4	2

Table 4: Simulation result FTDD and TWK through scheduling rules

	DR	C_{max}	T_{max}	∑Tj	∑Uj	∑Cj	$\sum W_j T_j$
FTDD	**SPT**	30	16	54	5	129	54
	CR	31	17	57	6	132	57
	EDD	31	17	60	5	135	60
TWK	**SPT**	30	26	94	6	129	94
	CR	33	25	100	6	135	100
	EDD	37	27	104	6	139	104

Based on the above simulation result a statistical analyses using the analysis of variance (ANOVA) procedure in order to study the effect of due-date assignment methods and scheduling rules on the performance of the job shop system considered. Two factors ANOVA methods are used where in due-date assignment method and scheduling are the two factors. The least significant difference (LSD) method was used for performing pairwise comparisons in order to determine which means differ from the other.

7.1. Statistical Analysis

A two factor Analysis of variance of the experiment result is performed to identify the effect of due-date assignment methods and scheduling rules on the performance of the job shop system. The least significant difference (LSD) method was used for performing pairwise comparisons in order to determine which means differ from the other. The ANOVA results are displayed in Table 5 from the analysis; we can draw the following conclusions. It is evident that the percentage of jobs late depends on:

a) The dispatching rule used
b) The due-date assignment method employed(FTDD and TWK)
c) The interaction between the dispatching rule and the due-date assignment method

From the interaction matrix (Due date*Dispatching rule) and plots of their mean values we can draw a conclusion that the FTDD method result less value than TWK for all scheduling categories used.

Table 5: A two factor variance analysis result

Tests of Between-Subjects Effects					
Source	**Dependent Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**
Corrected Model	C_{max}	36.000[a]	5	7.200	.
	T_{max}	133.333[a]	5	26.667	.
	T_j	2756.833[a]	5	551.367	.
	U_j	1.333[a]	5	.267	.
	C_j	76.833[a]	5	15.367	.
	W_jT_j	2756.833[a]	5	551.367	.
Intercept	C_{max}	6144.000	1	6144.000	.
	T_{max}	2730.667	1	2730.667	.
	T_j	36660.167	1	36660.167	.
	U_j	192.667	1	192.667	.
	C_j	106400.167	1	106400.167	.
	W_jT_j	36660.167	1	36660.167	.
Duedate	C_{max}	10.667	1	10.667	.
	T_{max}	130.667	1	130.667	.
	T_j	2688.167	1	2688.167	.
	U_j	.667	1	.667	.
	C_j	8.167	1	8.167	.
	W_jT_j	2688.167	1	2688.167	.
Disprule	C_{max}	16.000	2	8.000	.
	T_{max}	1.333	2	.667	.
	T_j	64.333	2	32.167	.
	U_j	.333	2	.167	.
	C_j	64.333	2	32.167	.
	W_jT_j	64.333	2	32.167	.
Duedate*Disule	C_{max}	9.333	2	4.667	.
	T_{max}	1.333	2	.667	.
	T_j	4.333	2	2.167	.
	U_j	.333	2	.167	.
	C_j	4.333	2	2.167	.
	W_jT_j	4.333	2	2.167	.
Error	C_{max}	.000	0	.	
	T_{max}	.000	0	.	

Table 6: Estimated Mean Value with Due Date* Dispatching Rule matrix

Dependent Variable	Due date	Dispatchin g rule	Mean
Cmax	FTDD	CR	31.000
		EDD	31.000
		SPT	30.000
	TWK	CR	33.000
		EDD	37.000
		SPT	30.000
Tmax	FTDD	CR	17.000
		EDD	17.000
		SPT	16.000
	TWK	CR	25.000
		EDD	27.000
		SPT	26.000
Tj	FTDD	CR	57.000
		EDD	60.000
		SPT	54.000
	TWK	CR	100.000
		EDD	104.000
		SPT	94.000
Uj	FTDD	CR	6.000
		EDD	5.000
		SPT	5.000
	TWK	CR	6.000
		EDD	6.000
		SPT	6.000
Cj	FTDD	CR	132.000
		EDD	135.000
		SPT	129.000
	TWK	CR	135.000
		EDD	139.000
		SPT	129.000
WjTj	FTDD	CR	57.000
		EDD	60.000
		SPT	54.000
	TWK	CR	100.000
		EDD	104.00
		SPT	94.00

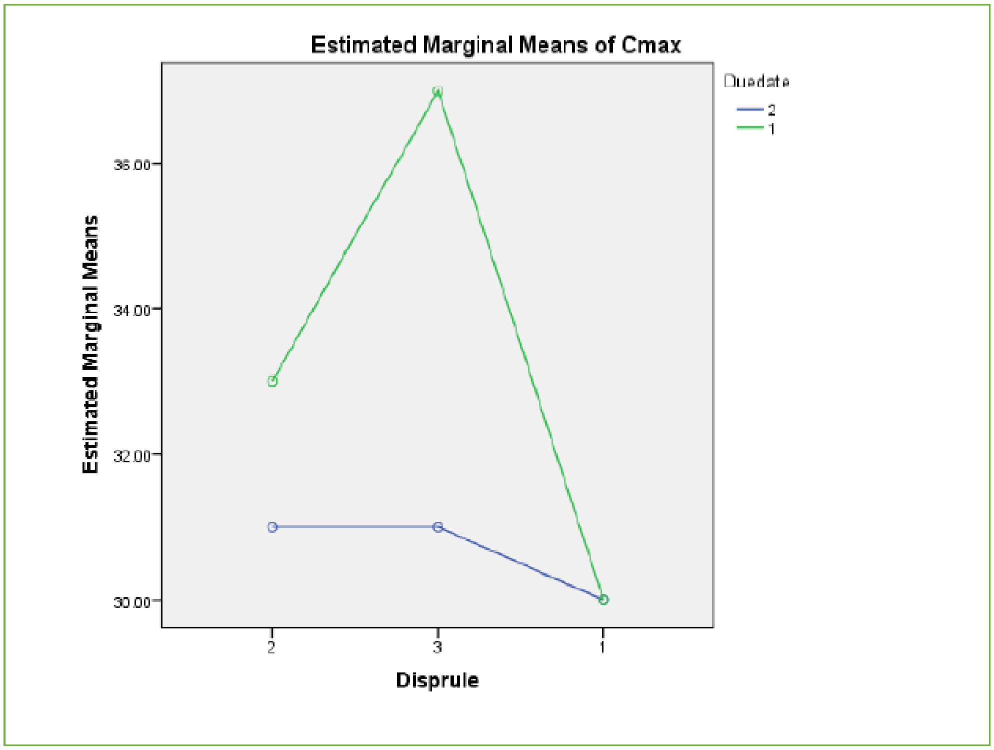

Figure 1: Estimated Marginal Means of Cmax

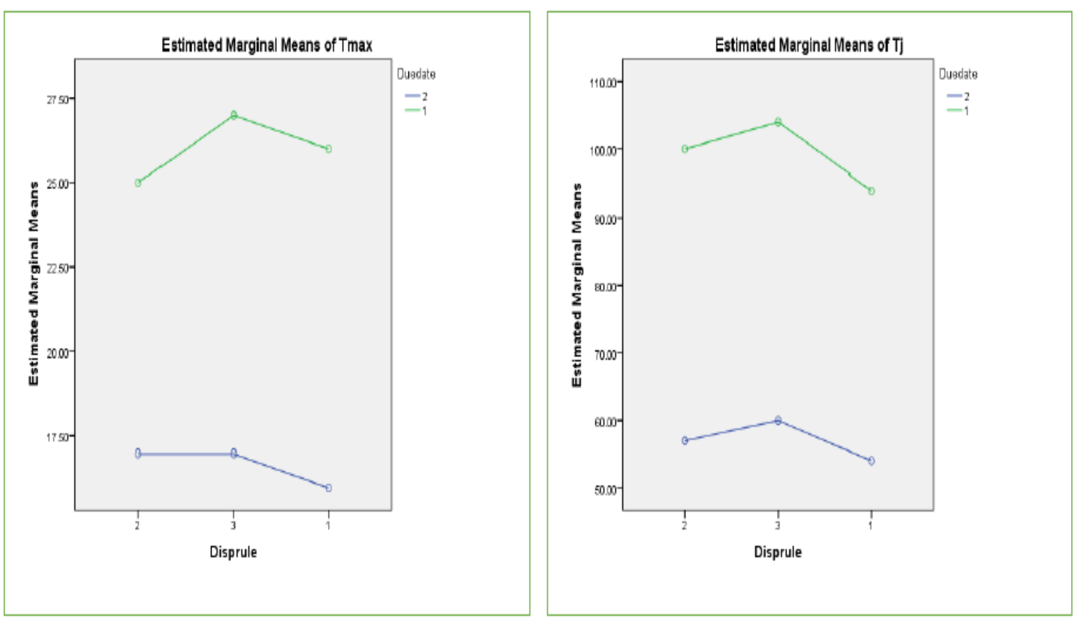

Figure 2: Estimated Marginal Means of Tmax and Tj

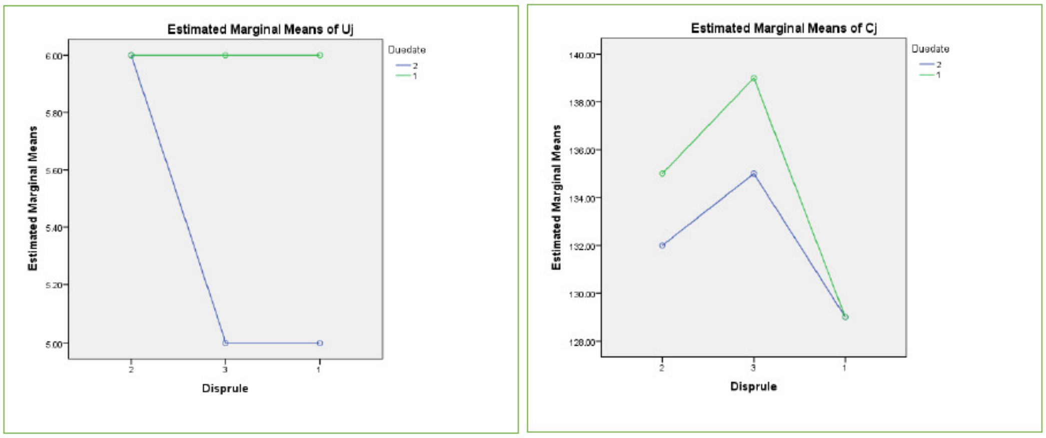

Figure 3: Estimated of Marginal Means of Uj and Cj

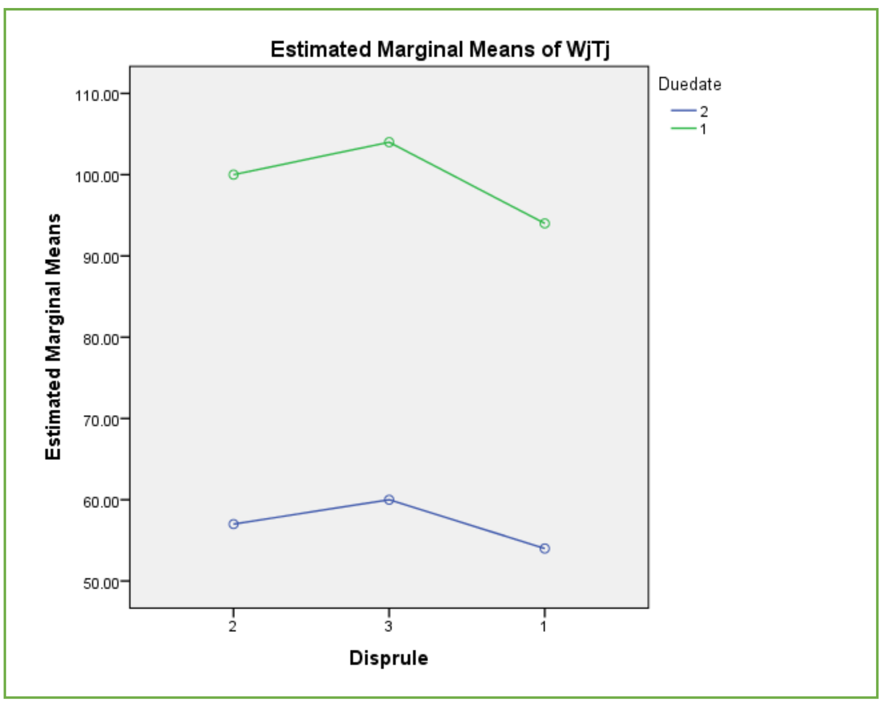

Figure 4: Estimated Marginal Means of WjTj

8. CONCLUSIONS

Researches in job shop production system simulation studies presented that the assignment of due dates is done in an environment that differs greatly from the environment in the production control department [7]. One difference is in the setting of due dates. In the operating situation, each job has many characteristics that may be combined to produce a due date; many, if not all, of non-quantities factors associated with real jobs are not present in simulation studies [7]. In this paper the simulation analysis considers the actual environment in the production control of the case company; this will reduce and compensate any arbitrary assumptions made. The purpose of this study is to investigate two due date assignment models FTDD and TWK based on the three scheduling rules (SPT, CR and EDD) in a job shop production system. An attempt to find functional interaction between due-date assignment method and dispatching rule is accomplished through the use of simulation and comparison analysis. The performance of the system is evaluated based on maximum tardiness, number of tardy jobs and total weighted tardiness. Based on the findings of the study it can be concluded that the combined effect of scheduling rules and due-date assignment methods result more reliable due dates with FTDD model compared with TWK through SPT, EDD and CR dispatching rules in a job. Therefore, HMMBI is recommended to use FTDD whenever there is a need to combine scheduling rules with due-date assignment methods.

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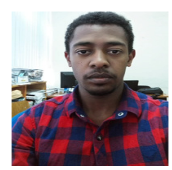

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