

INTEGRATION OF SIMULATION, ANALYSIS OF VARIANCE AND GOAL PROGRAMMING FOR MINIMIZATION OF MAKESPAN AND TARDINESS

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Abstract

This paper presents an integrated computer simulation, goal programming and analysis of variance algorithm to solve the job shop scheduling problem with multiple objectives. The proposed algorithm is applied to an actual textile dyeing, printing and finishing workshop for minimization of tardiness and makespan in which we first, simulate the workshop operation using Awesim (SLAM II) language. The proposed simulation model itself enables managers to find schedule of jobs on machines given a defined combination of decision parameters which provide the smallest completion time of jobs. We then, utilize design of experiment (DOE) for determining the decision parameters in order to estimate the effect of both qualitative and quantitative factors through metamodeling. A goal programming model is used to find the optimum values of decision variables subject to a set of technical and managerial constraints. Additionally, we conduct a sensitivity analysis since the managers are tending to know the impact of RHS (right hand side values). The significance and advantage of the proposed algorithm is its concentration on two main managerial objectives simultaneously whereas previous studies were able to consider a single criterion. Although we illustrate the performance of the proposed algorithm by its application in a small case, this general procedure has this advantage to be applicable in large scale problems.

Keywords: Goal programming, Minimization, Analysis of Variance, Makespan, Tardiness, Multi-criteria decision making.

Presenting Author's biography

Azadeh Dabbaghi received her B.Sc. in 2005 from the industrial management department and is currently pursuing her master's degree in industrial (system) engineering at the University of Tehran. She is a PhD candidate and her research directions are: Multi Criteria Decision Making (MCDM), Multi Attribute Utility Theory (MAUT), Scheduling and Simulation optimization. She is now a senior expert in the administration directorate at NIOC (National Iranian Oil Company)



1 Introduction and Literature search

In competitive and complex industries a manager should make the best decision regarding the numerous criteria deals with. One of the basic and complicated problems that a production manager encounter, is to find a suitable schedule of n jobs on m machines. Scheduling is allocation of resources for performing a set of jobs at a certain time [1]. One type of scheduling problem is job shop scheduling. Linear programming and branch & bound are methods to find the optimal solution for this kind of problems but having n jobs with more than 3 operations on 2 machines lead the problem to be NP hard [2]. So these optimization methods can be utilized for small problems. In recent years, numerous methods such as Genetic algorithm, Tabu search, Simulated annealing, Neural network, Machine learning and other heuristics have been proposed for solving such problems. A review on conventional and new solution techniques has been done by [3].

Tavakkoli-Moghaddam, R. & Daneshmand-Mehr, M. [4] proposed a computer simulation based on network modeling using "Awesim" language to solve job shop scheduling problem. In addition the output of the model contains variable information about machine utilization, average queue length and average waiting time of jobs for each machine. The results have shown that this method is an efficient tool for solving job shop problems with minimizing make span.

Veral, E.A [5] has employed response-surface mapping methodology via regression analysis for reliable and static due date setting in multi-job shops.

Üstün, S. et al. developed a simulation model using Awesim (SLAM II) language in a production line bottleneck problem minimizing makespan [6].

Azadeh, A. & Maghsoudi, A. [7] integrated a computer simulation model of a large steelmaking workshop with design of experiment and Tabu Search in order to optimize the performance of it.

Metamodel is specified as a regression model where independent regression variables are simulation input parameters and the dependant variable is the simulation response of the interest [8]. Blanning, W.R. [9] has described the construction and implementation of metamodels for the first time. Madu, C.N. [10] has summarized major benefits of metamodeling.

Generally, a metamodeling study is carried out in three steps [11]:

1. Estimation involves specifying the type of metamodel and selecting an experimental design for simulation data collection to estimate the parameters of the metamodel.
2. Analysis involves checking the validity of assumptions, carrying out the test for lack of fit and performing the analysis of variance.

3. Validation involves checking the metamodel against independent data.

Tekin, E.; Sabuncuoglu, I. [12] have reviewed theory and applications of simulation optimization.

The significance of our work is presented in tab. 1.

Tab. 1 A comparison of the presented algorithm and other studies

specifications	Opt ¹	CBQF ²	MCDM ³	SUS ⁴	SA ⁵	AEODF ⁶
methods						
Our integration algorithm	√	√	√	√	√	√
ANOVA analysis	—	—	—	—	—	√
Simulation modeling	—	—	—	√	—	—
Mathematical programming	√	—	√	—	√	—
Dengiz, B.[21]	√	—	—	—	√	√
Tunali, S. [13]	—	√	—	—	—	√
Tavakkoli R. [4]	—	—	—	√	—	—

1- Opt: optimization,

2-CBQF: Considering both qualitative and quantitative factors,

3-MCDM: Multi-criteria decision making,

4-SUS: Scheduling using simulation,

5-SA: Sensitivity analysis,

6-AEODF: Analyzing the effect of decision factors

The organization of this paper is as follows: in *section 2* we define the applied case. In *section 3* the framework for metamodeling process involving both kinds of qualitative and quantitative factors is described. *Section 4* explains the multi criteria decision making considering JIT concept. The structure of the simulation model and its related assumptions are addressed in *section 5*. Then we optimize the simulation model in *section 6*. At the end we conduct sensitivity analysis in *section 7*.

2 Case study: a textile shop for fabric dyeing, printing and finishing

This study was carried out at a textile shop located in Yazd, Iran. This shop includes four main machines in three units which are as follows:

1. **Dyeing**: the available dyeing machines can load equal or more than 400 kg. This process is being done with 2 Low-Technology (LT) machines; each machine requires a controller worker. Replacing these two LT machines with High-Technology (HT) ones decreases the processing time of jobs in this unit and requires only one worker.
2. **Printing**: Speed of this unit is adjustable through the temperature regulation of printing machine between 90-110 ° C. Proportionally the rolls

velocity should vary between 1000-1200 RPMs. This unit contains 1 printing machine.

3. **Finishing:** Speed of this unit is adjustable through the temperature regulation of stenter machine between 100-120 ° C. Proportionally The machine can finish 25-40 meters fabric per minute. There is one stenter in this unit.

Six various kinds of fabric with special specifications are processed in this shop as shown in tab. 2. Each of them may require some or all these machines in some specific sequences.

We can propose this production process in schematic figure1.

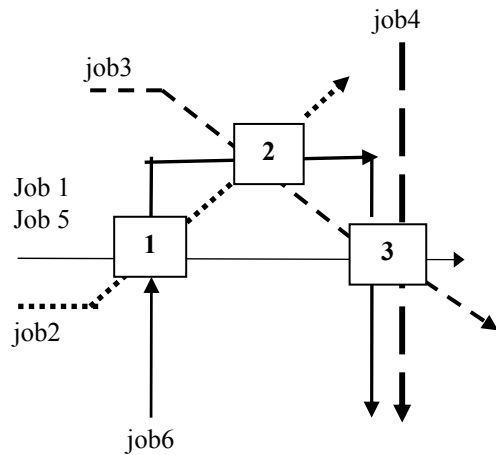


Fig. 1

Tab. 2 Data of the workshop 6 job 3 machine scheduling problem

Job number	Machine sequence	Processing times (mean of normal distribution)	Due dates
1	1,3	7.4 , 5.1	14
2	1,2	11.8 , 1.9	20
3	2,3	1.25 , 2.85	6
4	3	8.1	27
5	1,3	12.4 , 7.9	27
6	1,2,3	8.2 , 2.8 , 1.52	18

3 Metamodeling involving both quantitative and qualitative factors

Tunali, S.; Batmaz, I. [13] defined qualitative and quantitative factors as “Factors identifying the distinct classes, categories or levels to which the observations belong”. They proposed a framework for metamodeling process involving both kinds of factors. They presented the following metamodel considering the main effects and interactions between levels of qualitative factors (z) and the quantitative factors(x):

$$y = \theta_0 + \sum_{i=1}^k \alpha_i x_i + \sum_{i < j} \beta_{ij} x_i x_j + \sum_i \gamma_i z_i + \sum_i \sum_j \delta_{ij} x_i z_j$$

$$+ \sum_l \sum_{i < j} l_{ijl} x_i x_j z_l + \sum_l \sum_i \eta_{il} x_i^2 z_l + \varepsilon_0$$

In this equation different levels of a qualitative factor are represented by the following indicator variable (z):

$$z_{ij} = \begin{cases} 1, & \text{If the } j \text{ th level of the qualitative factor } i \text{ is used,} \\ 0, & \text{otherwise;} \end{cases}$$

In which $i=1, \dots, n$ and $j= 1, \dots, n_i$. Each qualitative factor will be represented by (n_i-1) indicator variables in the metamodel. Where:

y = response variable,

θ_0 = overall mean response or regression intercept,

α_i = main effect of quantitative factor i,

β_{ij} = two-factor interaction between quantitative factors i and j with $i \neq j$,

γ_i = main effect of the indicator variable i,

$\delta_{ij}, l_{ijl}, \eta_{il}$ = interactions among the quantitative and the levels of qualitative factors,

ε_0 = fitting error of the regression model.

4 Multi-criteria decision making considering JIT concept

According to just in time (JIT) approach, production managers should consider more than one criterion in scheduling problems. When we use two criteria (which usually makes the problem more realistic) instead of using a single criterion, one criterion can be chosen to represent the manufacturer’s concern (such as Minimizing flowtime, complete time, makespan and etc.) while the other could represent consumers concern (such as Minimizing number of tardy jobs, total tardiness, earliness and etc.)[14].

In a survey Wisner and Siferd discovered that although meeting due dates (i.e. on time delivery) was the most important scheduling objective, only 58% of industrial schedulers managed to deliver on time [15]. Obviously there is a need for paying more attention to improve delivery performance, especially in the JIT environment.

Computational results on five test problems and comparing them with other results reported in the literature (genetic algorithm, Branch and Bound algorithm, Linear programming) have shown that simulating a (especially large scale) jobshop problem using Awesim language could be an efficient tool to find optimal (or near optimal) solutions with the objective of minimizing makespan [4].

In this case study the managers’ first preference is minimizing makespan because this objective can lead to:

- Minimizing completion time of jobs

- Decrease of working time of the set of all machines which results in lower machine depreciation and other related costs
- sooner completion of jobs as well as the preparation of shop for the sooner entrance of new jobs

As our “most significant objective (makespan)” and “the case study operation conditions” were similar to the simulation network proposed by [4] we adapt their model for our use in a way that tardiness of each job (using due dates) can be calculated as well as its total makespan. Calculating “Total Tardiness” is due to the secondary objective of the managers as a result of their emphasis on On-Time delivery to customers (based on JIT approach).

It is important to point out that we propose an optimization module in our integrated algorithm which uses a Goal Programming; this means that given the managers’ priorities on these two criteria (objectives) we can find the best schedule considering possible changes in decision parameters (factors). So we do not pretend that the simulation model we employed can individually provide the best schedule in terms of both objectives simultaneously (there is no evidence that it can be an efficient tool for solving this bicriteria scheduling problem).

5 Simulation modeling of the case operation

Here the important assumptions made in the present simulation study have been listed out.

- For jobs:
 - All the jobs are available at the start time of the scheduling problem.
 - One job can not be allocated more than one machine at the same time.
 - The processing time of each job on each machine (table 1) includes set up times, transportation time and processing times of detailed machines between each two main processes.
- For machines:
 - All machines are available and ready to process the allocated jobs at the start time of the scheduling process.
 - Each machine can not process more than one job simultaneously.

Fig.2 illustrates the simulation modeling of the workshop with 6 jobs and 3 machines. We use Awesim (visual slam II) language to model this job shop scheduling problem. One of the main advantages of Visual SLAM is that its structure is based on the network modeling and it is very easy to add or remove attributes of the system. The second advantage is that it is a good tool for the manager of the system to obtain statistical reports in order to make good decisions for different experiments. The output of such a model contains valuable information about machine utilization, idle time for each machine, the average queue length of jobs for each machine, and

the average waiting time of jobs for each machine. These outputs can also give us the sequence of jobs on each machine in job shop scheduling problems [4].

This model includes a network and a subnetwork. The jobs are considered as entities and entered to shop through 6 *create* nodes. A general explanation of how this model works from the starting point to the end (*terminate node*) have proposed in [4]. In order to consider due dates of jobs, we define an extra *attribute* for each job. The value of tardiness for each job (which is a positive number) is calculated and then automatically will be added to the desired data base (an excel file) using *Write* node. Pritsker, A. [16] has explained all these nodes, attributes, variables and etc. The average queue length for each machine is available in summary of simulation output. Stenter machine (in finishing unit) has the highest average queue length and it seems reasonable because of the majority in utilizing this machine. The outputs of several independent runs have shown us that this machine can be considered as a bottleneck. So it means that increasing the number of this machine may be considered as a managers’ decision parameter. Control statements for proposed job shop problem are shown in appendix 1.

6 Simulation optimization

6.1 Developing the metamodel

In this study two response variables are considered. **First:** M which is the Makespan of workshop (i.e. the maximum completion time of all jobs), **second:** Total-T which is the total tardiness (sum of tardiness of each job-if any)

The workshop managers consider the following four factors as decision making parameters (or parameters which can be changed):

- 1) X_1 : a binary variable that represent the specification of dyeing machines.

$$X_1 = \begin{cases} 0 & \text{existing LT (Low Technology) machines} \\ 1 & \text{replacing them with HT (high technology) ones} \end{cases}$$
- 2) $90 \leq T_2 \leq 110$; A continuous variable represented the temperature of the printing machine.
- 3) $100 \leq T_3 \leq 120$; A continuous variable represented the temperature of the stenter machine.
- 4) N_3 : number of stenter machine (integer variable $N_3=1$ or 2)
- 5) Z: A qualitative factor which defines the workshop dispatching rule. This variable can have one of these levels:

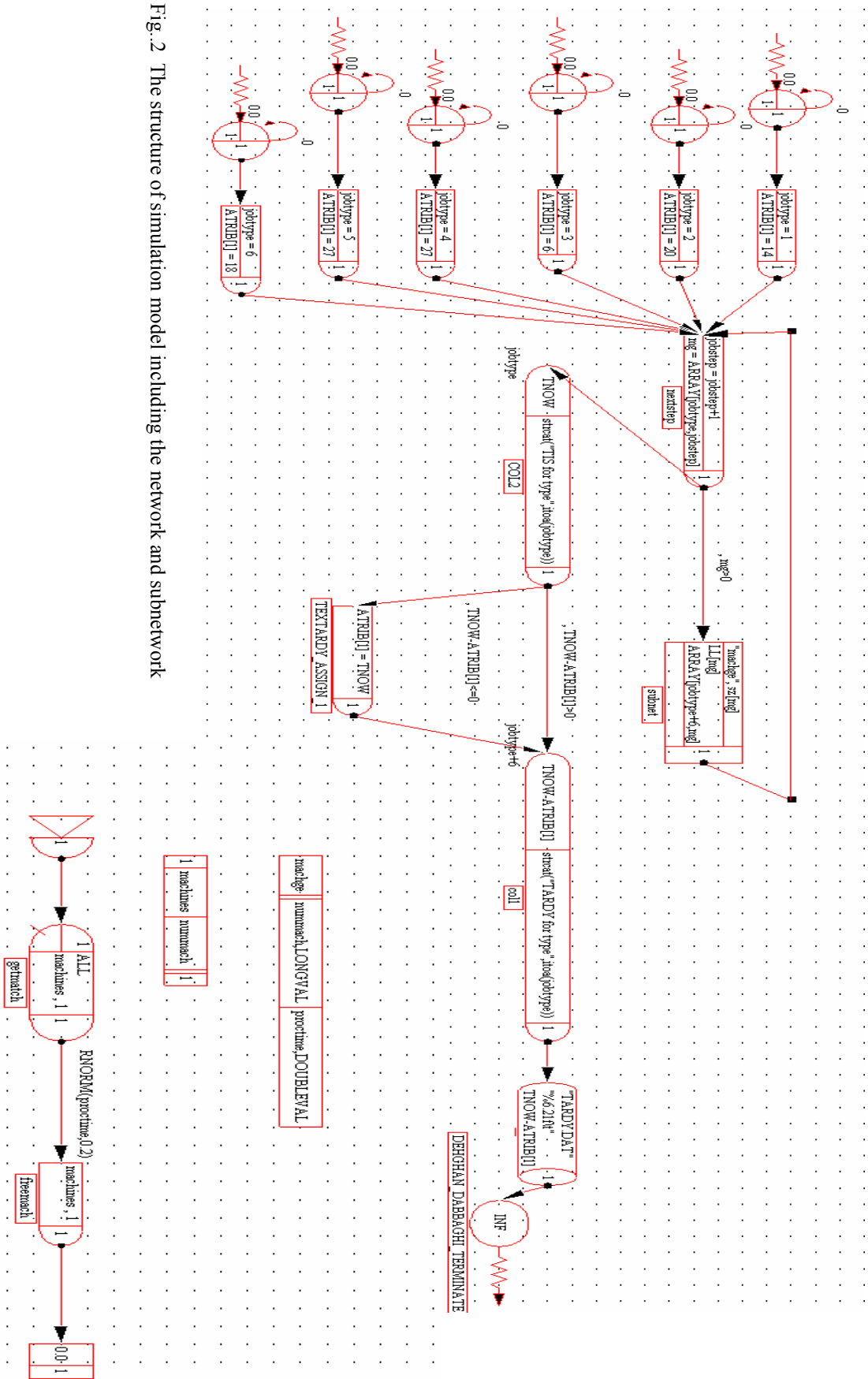


Fig.2 The structure of simulation model including the network and subnetwork

- **FCFS**: First Come First Serves
- **LCFS**: Last Come First Serves
- **SPT**: Shortest Processing Time
- **EDD**: Earliest Due Date
- **OPN/P**: remaining steps of operation per processing times

A general overview on these rules can be found in [17] & [5] and other scheduling books. Among different theoretical rules, we have selected these five rules because of their highest effect on responses through numerous test simulation runs and the ease of their application in real situation of workshop.

Tab. 3 Specification of the considered factors

Factor	Name	Type	Number of levels	Level values
A	X ₁	Qualitative	2	0,1
B	T ₂	Quantitative	2	90,110
C	T ₃	Quantitative	2	100,120
D	N ₃	Quantitative	2	1,2
E	Z	Qualitative	5	FCFS, LCFS, SPT, EDD, OPN/P

The above factors have defined and fixed effects on responses of the simulation model. These factors and their levels are summarized in Tab. 3.

All the combinations of the five independent factors are considered through a $5 \times 2^4 = 80$ full factorial design. Each combination was run for 3 independent replications. Total 240 outputs of the full factorial experimental design based on 4 quantitative factors each in two levels, a qualitative factor in five levels and 3 replications were collected in database and fed into the metamodel.

Tab. 4 partial results of running experiments

Experiment number	X ₁	T ₂	T ₃	N ₃	Z	M	TOTAL-T
1	0	110	100	2	FCFS	29.81	9.72
2	1	110	120	1	EDD	25.28	5.36
3	1	110	100	1	SPT	35.13	28.80
4	0	90	100	1	LCFS	35.17	37.43
5	0	90	120	2	SPT	30.60	5.22
6	0	90	100	2	OPN/P	29.80	10.96
7	1	90	100	2	FCFS	23.65	3.03
8	0	90	120	2	FCFS	26.10	6.25
...							
...							
238	1	90	120	2	SPT	25.53	0.00
239	1	110	120	2	OPN/P	19.96	1.25
240	1	110	100	1	FCFS	34.94	40.99

Although considering center points for T₂ and T₃ increases the precision of our design, this requires a lot of extra runs. In this study we use only the maximum and the minimum level of these factors. So the effect of intermediate values can be taken into account through final mathematical programming. A similar procedure has been employed previously by [3]. The partial results of running these 240 experiments are shown in Tab. 4.

We encountered the following two problems when we fitted the result of experiments in the metamodel proposed in section 3 using DOE command of MINITAB software:

- 1) This design is not orthogonal. So MINITAB notes that no storage of results or further analysis will be done. We can give an operational definition of orthogonality. First, form the design matrix associated with your model. Suppose v and w are two columns of this matrix. These two columns are orthogonal if: $\sum ViWi = 0$. If all pairs of columns, v and w, associated with different terms in the model are orthogonal, then the design is orthogonal.
- 2) Irrespective of the first problem, we would like to find a regression equation in which we can analyze the effects of separate levels of qualitative factor (Z) and their interactions with each of other factors. Considering a single factor Z with 5 levels can not meet our need.

We find the solution of both problems in “MINITAB help”: “The analysis of covariance can not be correctly done in designs that are not orthogonal. Analyze these non-orthogonal examples with the Regression command, or the General Linear Model command using indicator variables along with the covariates.”

We employ 5 indicator variables (Z₁, Z₂... Z₅) which represent the levels of qualitative factor (Z) in the regression analysis. Analyzing TOTAL-T and M versus X₁, T₂, T₃, N₃, Z₁, Z₂, Z₃, Z₄ and Z₅ including terms in the model up to order 3 (this assumption is due to the limitation of Lingo software in the number of non linear variables) have shown us that Z₅ is highly correlated with other variables. Consequently, Z₅ and other related terms have been removed from the equation automatically. (It is important to notify that in analyzing Total-T versus remaining variables, Z₄ and other related terms have been removed from the equation additionally). The Results of ANOVA for main, 2-way and 3-way interaction effects are shown in tab. 5 and 6.

Tab. 5 Analysis of Variance for M versus X₁, T₂, T₃, N₃, Z₁, Z₂, Z₃, Z₄

	Degree of freedom	Adj. sum of square	Adj. Mean square	F-ratio	P-value
Main Effects	8	796.078	99.51	3901.6	0.00
2-Way Interactions	22	250.622	11.39	446.67	0.00
3-Way Interactions	28	142.305	5.0823	199.27	0.00
Residual Error	181	4.616	0.0255		
Total	239				

S = 0.159701 R-Sq = 99.91% R-Sq(adj) = 99.88%

Tab.6 Analysis of Variance for TOTAL-T versus X₁, T₂, T₃, N₃, Z₁, Z₂, Z₃

	Degree of freedom	Adj. sum of square	Adj. Mean square	F-ratio	P-value
Main Effects	7	10049.2	1435.60	982.38	0.00
2-Way Interactions	18	3332.4	185.13	126.69	0.00
3-Way Interactions	22	907.9	41.27	28.24	0.00
Residual Error	144	210.4	1.46		
Total	191				

S = 1.209 R-Sq = 99.49% R-Sq(adj) = 99.32%

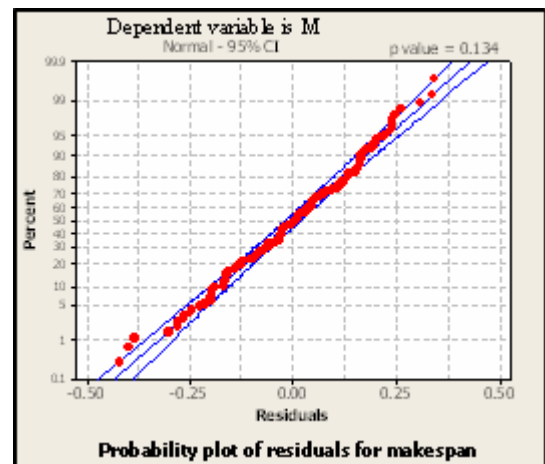
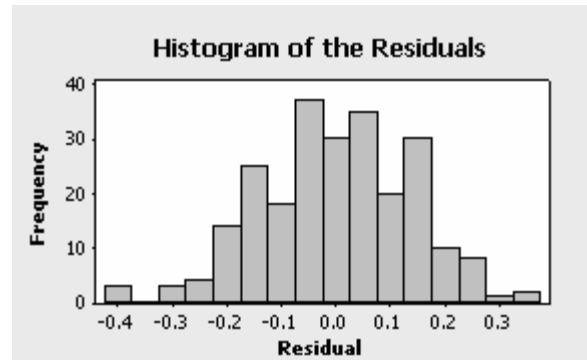
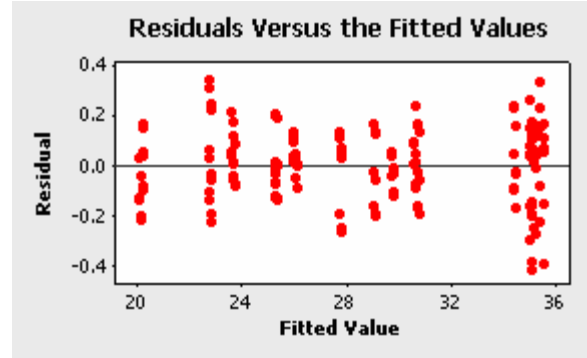
The regression models themselves were also found to be significant (p = 0.000). Detailed information of analyzing M and TOTAL-T versus selected terms is shown in appendix 2. The ANOVA analysis and the following residual plots (fig 3.1 and fig 3.2) can show us that the assumptions about error components are satisfied (p > 0.05 shows the normal distribution of residuals). Because the factors were chosen as fixed effects, F ratio for all effects is the mean square of the effect over the mean square of the residual error. Furthermore, p value shows the level of significance (α) of which the null hypothesis is accepted.

By referring to the analysis of variance (ANOVA) table, we eliminate the terms which have not a significant impact (p>0.05) on response variable; in other words, the terms which have the greatest impact on response variables are chosen.

Finally the regression equations for two different responses are estimated as follows:

$$M = 96.9009 + 59.1553X_1 - 0.0118T_2 - 0.55T_3 - 23.509N_3 - 0.0146Z_1 - 33.8178Z_2 - 33.78Z_3 - 33.78Z_4 - 0.525X_1T_3 - 33.32X_1N_3 + 1.036X_1Z_2 + 0.917X_1Z_3 + 0.917X_1Z_4 + 0.176T_3N_3 + 0.289T_3Z_2 + 0.291T_3Z_3 + 0.29T_3Z_4 + 18.9N_3Z_2 + 18.87N_3Z_3 + 18.87N_3Z_4 + 0.27X_1T_3N_3 - 0.0182X_1T_3Z_2 - 0.0187X_1T_3Z_3 - 0.0187X_1T_3Z_4 + 0.78X_1N_3Z_2 + 0.874X_1N_3Z_3 + 0.874X_1N_3Z_4 + 0.000049T_2T_3N_3 - 0.1418T_3N_3Z_2 - 0.14235T_3N_3Z_3 - 0.14235T_3N_3Z_4$$

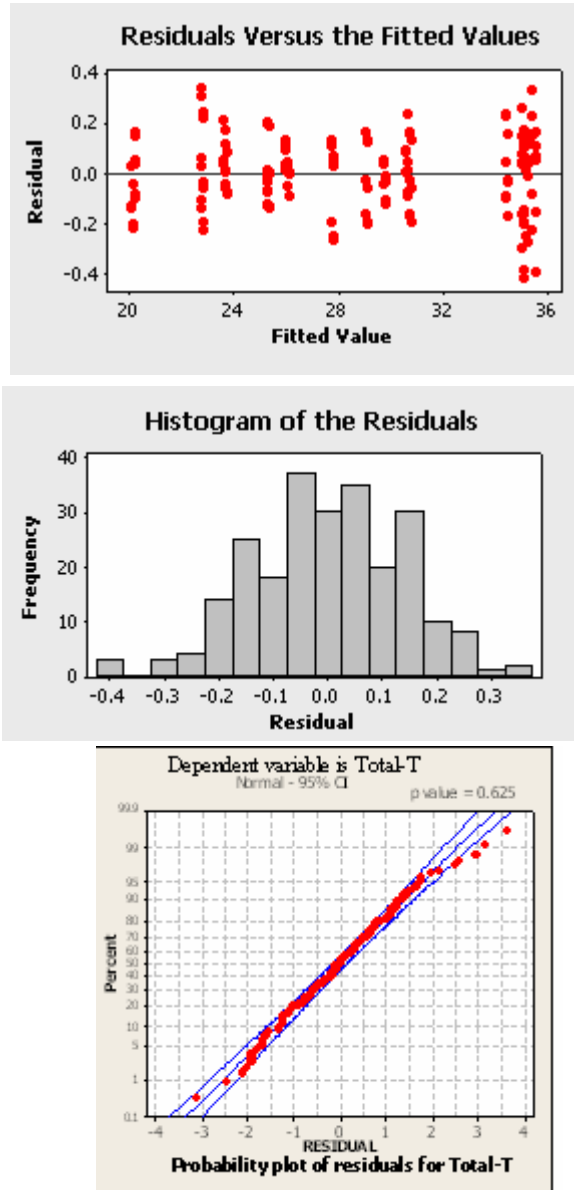
Fig. 3.1 Residual plots for M



$$T = 260.415 + 98.1873X_1 - 0.0336T_2 - 2.009T_3 - 107.946N_3 + 54.07Z_1 + 68.6058Z_2 - 21.8106Z_3 - 0.87X_1T_3 - 65.075X_1N_3 + 54.089X_1Z_2 - 19.26X_1Z_3 + 0.85T_3N_3 - 0.38T_3Z_1 - 0.57T_3Z_2 + 0.1979T_3Z_3 - 29.69N_3Z_1 - 43.66N_3Z_2 + 14.49N_3Z_3 + 0.55X_1T_3N_3 - 0.34X_1T_3Z_2 + 0.128X_1T_3Z_3 - 8.329X_1N_3Z_2 + 2.448X_1N_3Z_3 + 0.218T_3N_3Z_1 + 0.37T_3N_3Z_2 - 0.131T_3N_3Z_3$$

In each of the above regression models, the interactions denote the effect of simultaneously changing the values of the corresponding decision variables on the response variable.

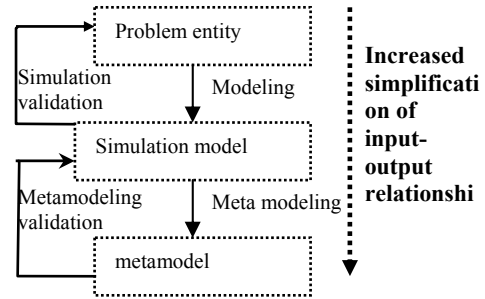
Fig. 3.2 Residual plots for TOTAL-T



6.2 Validation

Noordegraaf, A.V. et al [18] proposed the relationships among problem entity, simulation model and metamodel as shown in Fig.4. In this study verifying and validating the simulation model was the first step in the validation process.

Fig.4 Relationships among problem entity, simulation model and metamodel



The validity of a metamodel is determined by making many comparisons between the outputs of the metamodel and the simulation.

Tab. 7 Validation of the regression metamodel M

design points					w	y	ARE
X1	T2	T3	N3	Z			
0	90	100	1	SPT	34.936	35.224	0.0083
1	110	100	2	FCFS	23.658	23.642	0.0007
0	90	120	2	EDD	30.597	30.779	0.0059
0	110	100	1	EDD	34.936	35.085	0.0043
1	110	120	2	LCFS	25.197	25.328	0.0052
1	110	120	2	FCFS	19.958	20.157	0.0100
0	90	100	2	EDD	34.435	34.447	0.0003
0	90	120	1	FCFS	27.832	27.831	0.0000
0	90	120	2	SPT	30.735	30.779	0.0014
1	90	120	1	EDD	25.285	25.354	0.0027
The average ARE value is 0.0039							

Tab. 8 Validation of the regression metamodel Total -T

design points					w	y	ARE
X1	T2	T3	N3	Z			
1	90	100	1	LCFS	53.763	51.165	0.0480
0	90	120	1	SPT	11.150	11.243	0.0080
1	90	100	2	LCFS	1.897	3.805	1.0050
1	90	100	1	SPT	29.829	30.279	0.0150
0	110	120	1	LCFS	13.771	10.610	0.2300
0	110	100	1	SPT	33.531	32.406	0.0340
0	90	100	1	LCFS	35.344	38.466	0.0880
0	110	120	1	SPT	9.712	10.583	0.0900
1	110	100	1	FCFS	40.990	42.280	0.0310
0	90	120	1	FCFS	13.962	15.303	0.0960
The average ARE value is 0.164							

To decide whether to accept a specific model, we need a *criterion*. Some case studies use the *Absolute Relative Error* or *ARE*, $r(w,y) = |(w-y)/w|$, where simulation output is w and the metamodel output is y ; However, this measure is deficient if w may be zero [19].

In this study we use ARE as a measure for the validation of fitted matamodel. The metamodel was tested against simulation runs at 10 randomly selected design points. We consider both of the metamodels valid relative to the simulation due to calculating ARE as shown in the last column of Tab. 7 and Tab. 8 with the average value of 0.39% and 16%.

7 Optimization using goal-programming

We propose a goal programming model in which the managers' priorities over selected objectives are considered. The optimal configuration of decision variables (parameters) minimizes sum of weighted penalties (d_i is deviation from desired level of the objectives) subject to a series of technological and managerial constraints. The above mentioned goal programming model can be stated as follows:

$$\text{MIN} = 12d_1 + 10d_2 + d_3 \quad (1)$$

Subject to:

$$Z_1 + Z_2 + Z_3 + Z_4 = 1 \quad (2)$$

$$N_3 = K_1 + 2K_2 \quad (3)$$

$$K_1 + K_2 = 1 \quad (4)$$

$$96.9 + 59.1X_1 - 0.01T_2 - 0.5T_3 - 23.5N_3 - 0.01Z_1 - 33.8Z_2 - 33.78Z_3 - 33.7Z_4 - 0.5X_1T_3 - 33.3X_1N_3 + 1.03X_1Z_2 + 0.9X_1Z_3 + 0.917X_1Z_4 + 0.17T_3N_3 + 0.2T_3Z_2 + 0.29T_3Z_3 + 0.29T_3Z_4 + 18.9N_3Z_2 + 18.8N_3Z_3 + 18.87N_3Z_4 + 0.27X_1T_3N_3 - 0.02X_1T_3Z_2 - 0.02X_1T_3Z_3 - 0.02X_1T_3Z_4 + 0.78X_1N_3Z_2 + 0.874X_1N_3Z_3 + 0.87X_1N_3Z_4 + 0.000049T_2T_3N_3 - 0.14T_3N_3Z_2 - 0.14235T_3N_3Z_3 - 0.14T_3N_3Z_4 - d_1 = 19.95 \quad (5)$$

$$260.4 + 98.19X_1 - 0.03T_2 - 2.0T_3 - 107.9N_3 + 54.07Z_1 + 68.68Z_2 - 21.8Z_3 - 0.87X_1T_3 - 65.075X_1N_3 + 54X_1Z_2 - 19.2X_1Z_3 + 0.85T_3N_3 - 0.38T_3Z_1 - 0.57T_3Z_2 + 0.19T_3Z_3 - 29.69N_3Z_1 - 43.66N_3Z_2 + 14.49N_3Z_3 + 0.55X_1T_3N_3 - 0.34X_1T_3Z_2 + 0.128X_1T_3Z_3 - 8.329X_1N_3Z_2 + 2.4X_1N_3Z_3 + 0.22T_3N_3Z_1 + 0.37T_3N_3Z_2 - 0.13T_3N_3Z_3 - d_2 = 0 \quad (6)$$

$$T_2 + 11L_1 \geq 101 \quad (7)$$

$$T_2 + 10L_1 < 110 \quad (8)$$

$$T_3 + 11L_2 \geq 111 \quad (9)$$

$$T_3 + 10L_2 < 120 \quad (10)$$

$$2-X_1 + 3-L_1 + (3-L_2)(K_1 + 2K_2) - d_3 + d_4 = 9 \quad (11)$$

$$2(4.5 + 180-54)X_1 + 259K_2 \leq 300 \quad (12)$$

$$(3.1 + 6.61X_1) + (5.12 + 35.07 - 0.7639T_2 + 0.00419T_2^2) + (2.13 + 4.39K_2 + N_3(17.2 - 0.3336T_3 + 0.001629T_3^2)) \leq 17 \quad (13)$$

$$X_1, K_1, K_2, Z_1, Z_2, Z_3, Z_4, L_1, L_2 = 0, 1 \quad (14)$$

$$90 \leq T_2 \leq 110 \quad (15)$$

$$100 \leq T_3 \leq 120 \quad (16)$$

This model has been solved using *Lingo* software.

Constraint 2 is utilized to select one of the dispatching rules after solving GP model.

LINGO does not simply round or truncate values to come up with an integer answer. To solve these problems, LINGO performs a complex algorithm called branch-and-bound that implicitly enumerates all combinations of the integer variables to determine the best feasible answer to an IP model. Because of the extra computation time required by this algorithm, it is advised to formulate the problem using binary variables in away that avoids the use of integer variables whenever possible. We replace the integer variable N_3 with two binary variables through defining K_1 and K_2 (**constraints 3 and 4**).

Constraints 5 and 6: State the goal of reducing makespan and tardiness respectively in which the metamodels of section 6-1 are utilized.

Adding extra binary variables L_1 and L_2 to the model (constraints 7-10) is for considering this logical condition: "the required number of controller workers for each machine will be increased if we adjust the printing and stenter machines in higher temperatures." Several tests have shown us that if the temperature of printing machine is under 100°C it will require 3 control workers and if we adjust the temperature upper than 100, it is necessary to add more controllers regarding stenter machine if the temperature is below 110°C it will require 2 controllers but if for any reason we have to adjust the temperature upper than 110°C an extra worker will be added. Considering these conditions in mathematical programming model, could be stated as **constraints 7 and 8** for printing machine and constraints 9 and 10 for the stenter machine.

One of these conditions can be stated in the following logical (general) form: if $\delta=1 \rightarrow \sum a_j X_j \leq b$. This inequality can be represented by the constraint: $\sum a_j X_j + M\delta \leq M+b$, Where M is an upper bound for the expression: $\sum a_j X_j - b$ [20].

Constraint 11 explains the limitation of available controller workers. Manager's effort is to assign the jobs to existing 9 workers in order not to employ any extra worker unless the constraints allow. This constraint determines number of workers for each station

The values in the **12th constraint** Stands for the cash flow (budget) of the company for the investment on machineries. Coefficient of K_2 is an estimation price of stenter machine and the coefficient of X_1 is related to purchase and other related costs for installing and training in Rials (monetary

unit) that should multiply 1000000 in order to convert to real amounts.

Constraint 13 shows the average fixed cost related to machines in each unit per each meter of fabric. These costs were calculated considering price of machines, meters of fabric which is annually produced, estimated operating life time and etc. increasing the temperature of printing and stenter machine s will increases this cost as plotted in fig. 5, 6 (due to higher possibility of producing defective fabric, higher engine depreciation, higher wages of controller workers, higher preventive and maintenance costs and etc. The constraint insists on working in the breakeven point for achieving proper profit.

The first Constraint (objective function) shows the priorities: Minimizing makespan and tardiness as the first and second goals and applying the existing workers as the next. Coefficients of d_i s stand for degree of the goals fulfillment importance in accordance with manger's opinion.

Explanation of GP optimum results:

The goal programming model came up with this optimal combination of decision variables: $X_1= 0$, $T_2=110$, $T_3=110$, $Z_1 = 1$, $N_3 = 2$. It means that according to all managerial and technological constraints the best conditions for workshop are as follows:

- Temperature of printing machine should be adjusted on 110 °C.
- It is better to utilize two stenter machines instead of one that should be installed parallel to the first machine. The temperature of both machines should be adjusted on 110°C. (maximum temperature)
- It is recommended to work with two existing LT machines in dyeing unit.

- The best dispatching rule is FCFS (first come first serves).
- Managers should be able to provide 3 extra needed workers ($d_3=3$).

This optimization module allows mangers to find an alternative configuration of decision variables, whenever changing the system is required. The optimal sequences for machineries are shown in fig.7.

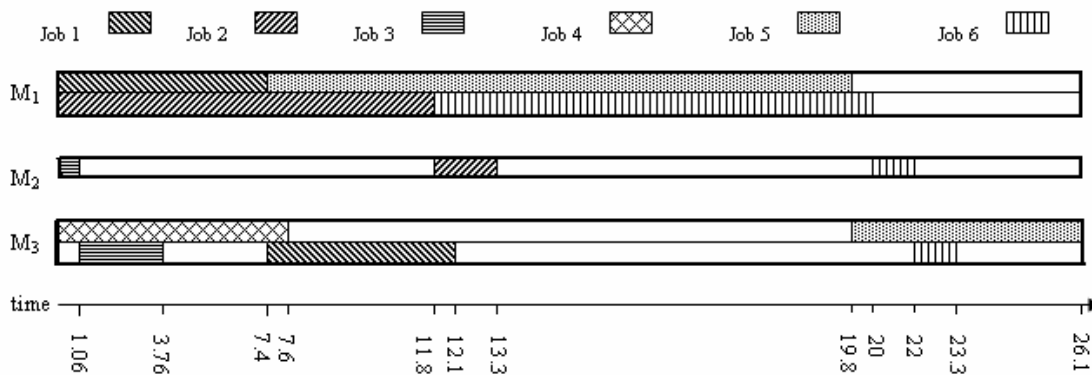
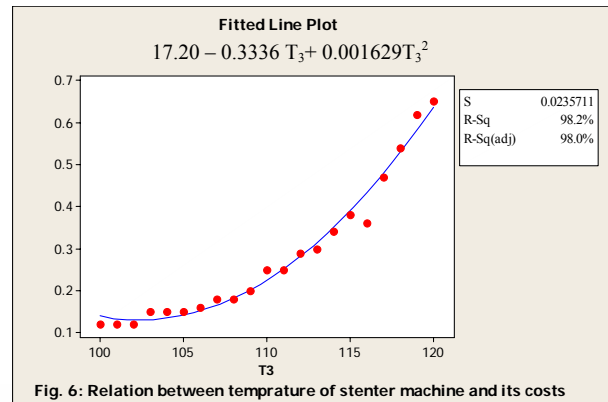
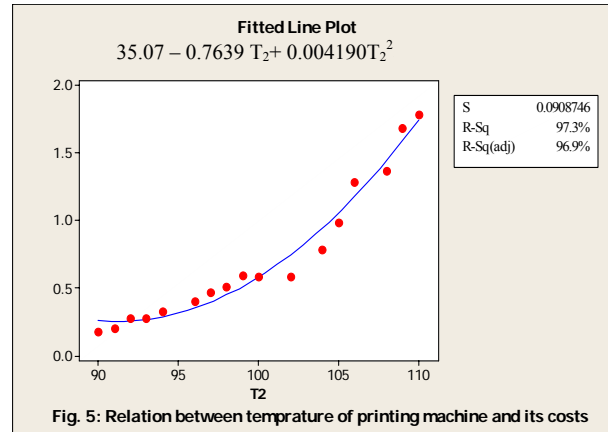


Fig.7 Gantt chart for the optimal solution of the problem

8 Sensitivity analysis

Since the Sensitivity analysis of multi criteria problems is complicated some what and the coefficients of the objective function of the presented multi criteria decision model (Goal programming) shows the priority of managers for meeting the specified requirements, optimum values of decision variables can not simply be judged and compared with their neighborhoods based on the acquired objective function value from solving the model.

According to the proposed model in section 7, the constraints 2-6 and 14-16 can not be manipulated as they are systematic constraints. The constraints 7-10 support the logical condition of the next constraints. Thus, the impact of changing RHS (right hand side value) on decision variables for 11th, 12th and 13th constraints is considerable.

For the 11th constraint no matter how many workers are existent, the present condition for dyeing machine is optimal. But the impacts of changing RHS for other

variables are collected in tab. 9.

Tab. 9 Sensitivity analysis of the constraint 11

RHS ₁₁	≤5	6	7	8	9	10	≥11
X ₁	-	0	0	0	0	0	0
T ₂	-	100	100	100	110	100	104
T ₃	-	110	120	110	110	120	120
Z	-	Z4	Z4	Z1	Z1	Z1	Z1
N ₃	-	1	1	2	2	2	2

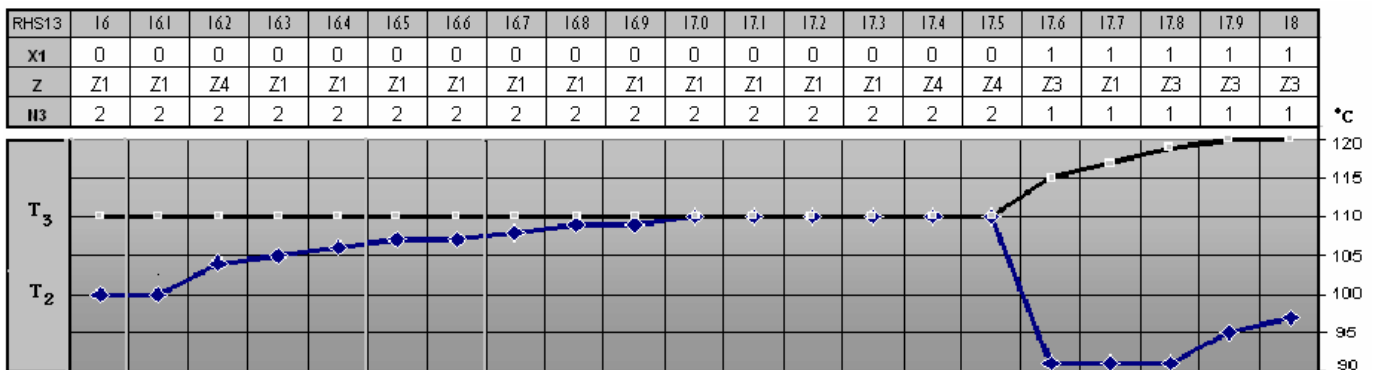
For the 12th constraint the impacts of changing RHS for the variables are presented in tab. 10:

Tab. 10 Sensitivity analysis of the constraint 12

RHS ₁₂	RHS ₁₂ < 259	RHS ₁₂ ≥ 259
X ₁	0	0
T ₂	110	110
T ₃	120	110
Z	Z4	Z1
N ₃	1	2

About changing the RHS of 13th constraint it should be noted that because of a very competitive market of the textile industry, this constraint is much more sensitive than others. And it can not be changed in a big interval. Thus, the RHS changes are practical only in the interval of [16-18] which are gathered in tab. 11.

Tab. 11 Sensitivity analysis of the constraint 11



9 Conclusions and further work

Today's importance of on time deliveries according to JIT concept makes managers to consider a desired set of extra "due date related" criteria in the workshop scheduling. These criteria can be stated as tardiness, number of tardy jobs, earliness and etc. considering extra objectives can dramatically increases the complexity of decision making

process. In this study we develop an integrated algorithm for a job shop production problem in a textile industry. **First**, we model the workshop operation with visual slam simulation software. **Second**, we optimize the simulation output utilizing a metamodel that involves qualitative and quantitative factors. Then according to JIT concept we minimize makespan (as the main objective) and total tardiness (as the secondary objective) subject to a set of managerial and technological constraints through a Goal Programming

model. The proposed procedure allows managers to find the best schedule for workshop operation considering the changes in decision parameters (factors which can affect operation specification). We assume a series of crisp values for due date of jobs in this study. Fuzzifying due date of jobs or other non-deterministic situations can be considered as further work.

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Appendix 1

Control statement for proposed job shop problem is as follows:

```

GEN,"mdehghan,adabaghi","simulation",2006/08/25,3,
YES,YES;
LIMITS,,3,3,1,3;
ARRAY,1,3,{1,3,0};
ARRAY,2,3,{1,2,0};
ARRAY,3,3,{2,3,0};
ARRAY,4,2,{3, 0};
ARRAY,5,3,{1,3,0};
ARRAY,6,4,{1,2,3,0};
ARRAY,7,3,{7.4,0,5.1};
ARRAY,8,3,{11.8,1.9,0};
ARRAY,9,3,{0,1.25,2.85};
ARRAY,10,3,{0,0,8.1};
ARRAY,11,3,{12.4,0,7.9};
ARRAY,12,3,{8.2,2.8,1.52};
INTLC,{LL[1],2},{LL[2],1},{LL[3],1};
INTLC,{sz[1],1},{sz[2],2},{sz[3],3};
EQUIVALENCE,{jobtype,LTRIB[1]},{jobstep,LTRIB[
2]},{mg,LTRIB[3]};
NET;
FIN;

```

Appendix 2

M versus X1, T2, T3, N3, Z1, Z2, Z3, Z4

Term	SE	T	P
Constant	0.03260	991.05	0.000
X1	0.03260	-59.62	0.000
T2	0.03260	0.11	0.915
T3	0.03260	-72.71	0.000
N3	0.03260	2.66	0.009
Z1	0.01630	-0.45	0.654
Z2	0.01630	95.86	0.000
Z3	0.01630	96.54	0.000
Z4	0.01630	96.54	0.000
X1T2	0.03260	-1.28	0.202
X1T3	0.03260	-23.63	0.000
X1N3	0.03260	-18.57	0.000
X1Z1	0.01630	0.94	0.349
X1Z2	0.01630	3.72	0.000
X1Z3	0.01630	3.04	0.003
X1Z4	0.01630	3.04	0.003
T2T3	0.03260	0.35	0.725
T2N3	0.03260	0.35	0.725
T2Z1	0.01630	0.75	0.456
T2Z2	0.01630	1.15	0.251
T2Z3	0.01630	1.15	0.251
T2Z4	0.01630	1.15	0.251
T3N3	0.03260	15.50	0.000
T3Z1	0.01630	0.45	0.654
T3Z2	0.01630	21.06	0.000
T3Z3	0.01630	21.14	0.000
T3Z4	0.01630	21.14	0.000
N3Z1	0.01630	0.45	0.654
N3Z2	0.01630	56.99	0.000
N3Z3	0.01630	56.31	0.000
N3Z4	0.01630	56.31	0.000
X1T2T3	0.01031	1.62	0.108
X1T2N3	0.01031	1.62	0.108
X1T2Z1	0.01630	-0.64	0.523
X1T2Z2	0.01630	-0.24	0.814
X1T2Z3	0.01630	-0.24	0.814
X1T2Z4	0.01630	-0.24	0.814
X1T3N3	0.01031	65.54	0.000
X1T3Z1	0.01630	-0.94	0.349
X1T3Z2	0.01630	-3.26	0.001
X1T3Z3	0.01630	-3.34	0.001
X1T3Z4	0.01630	-3.34	0.001
X1N3Z1	0.01630	-0.94	0.349
X1N3Z2	0.01630	5.55	0.000
X1N3Z3	0.01630	6.23	0.000
X1N3Z4	0.01630	6.23	0.000
T2T3N3	0.01031	-3.65	0.000
T2T3Z1	0.01630	-0.75	0.456
T2T3Z2	0.01630	-0.24	0.814
T2T3Z3	0.01630	-0.24	0.814
T2T3Z4	0.01630	-0.24	0.814
T2N3Z1	0.01630	-0.75	0.456
T2N3Z2	0.01630	-0.24	0.814
T2N3Z3	0.01630	-0.24	0.814
T2N3Z4	0.01630	-0.24	0.814
T3N3Z1	0.01630	-0.45	0.654
T3N3Z2	0.01630	-21.98	0.000
T3N3Z3	0.01630	-22.06	0.000
T3N3Z4	0.01630	-22.06	0.000

S = 0.159701

R-Sq = 99.91%

R-Sq(adj) = 99.88%

TOTAL-T versus X1, T2, T3, N3, Z1, Z2, Z3

Term	SE	T	P
Constant	0.17448	89.97	0.000
X1	0.17448	-7.87	0.000
T2	0.17448	-1.95	0.053
T3	0.17448	-48.23	0.000
N3	0.17448	-63.25	0.000
Z1	0.12338	14.46	0.000
Z2	0.12338	13.76	0.000
Z3	0.12338	-2.65	0.009
X1T2	0.17448	0.06	0.955
X1T3	0.17448	-4.22	0.000
X1N3	0.17448	-10.12	0.000
X1Z1	0.12338	0.73	0.469
X1Z2	0.12338	8.26	0.000
X1Z3	0.12338	-2.65	0.009
T2T3	0.17448	0.34	0.731
T2N3	0.17448	-0.46	0.647
T2Z1	0.12338	-0.26	0.793
T2Z2	0.12338	-0.00	1.000
T2Z3	0.12338	0.10	0.920
T3N3	0.17448	38.90	0.000
T3Z1	0.12338	-2.19	0.030
T3Z2	0.12338	-7.56	0.000
T3Z3	0.12338	2.65	0.009
N3Z1	0.12338	-11.51	0.000
N3Z2	0.12338	-13.76	0.000
N3Z3	0.12338	2.65	0.009
X1T2T3	0.08724	1.78	0.078
X1T2N3	0.08724	1.78	0.078
X1T2Z1	0.12338	-0.83	0.408
X1T2Z2	0.12338	0.00	1.000
X1T2Z3	0.12338	0.10	0.920
X1T3N3	0.08724	15.83	0.000
X1T3Z1	0.12338	0.11	0.909
X1T3Z2	0.12338	-6.89	0.000
X1T3Z3	0.12338	2.65	0.009
X1N3Z1	0.12338	0.35	0.729
X1N3Z2	0.12338	-8.26	0.000
X1N3Z3	0.12338	2.65	0.009
T2T3N3	0.08724	-0.57	0.567
T2T3Z1	0.12338	0.26	0.793
T2T3Z2	0.12338	-0.00	1.000
T2T3Z3	0.12338	-0.10	0.920
T2N3Z1	0.12338	-0.87	0.384
T2N3Z2	0.12338	-0.00	1.000
T2N3Z3	0.12338	-0.10	0.920
T3N3Z1	0.12338	4.42	0.000
T3N3Z2	0.12338	7.56	0.000
T3N3Z3	0.12338	-2.65	0.009

S = 1.20886

R-Sq = 99.49%

R-Sq(adj) = 99.32%