Strategy Formulation for Diagnostics of MRP Driven Production Line through Internal Benchmarking, Simulation and Regression analysis

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***Abstract*- A concise strategy is discussed in this paper to frame practical issues that are faced in the diagnostic analysis of a production line. A known model for performance cases is selected as benchmarking framework. Arrival rate, inter arrival time and batch size are selected as process parameters of the system to be analyzed. Focus of the paper is to formulate a diagnostic strategy for the MRP (Material Requirement Planning) driven production line and compare this line with the well known published model in the literature to observe the gaps. Moreover, performance of the strategy under varying input parameters through simulation and regression techniques is also analyzed.**

***Keywords*-** Simulation, Benchmarking, Regression, Statistical analysis, MRP

I. INTRODUCTION

Modern business requires competitive edge to stay in market and therefore production managers endeavor to utilize their facility to its capacity, reduce scrape rate and respond to their customers in full and on time [1]. For this reason production engineers always strive to select innovative and appropriate strategies. The selection of a production control strategy aims at tighter control over schedules and high profit margin with minimum possible investment. In the history of production control system many strategies were developed. In 1960's Joseph Orlicky devised a new production control system: Material Requirements Planning or MRP which was successfully implemented in over 8,000 companies by 1981 [2]. However, a few issues were found in MRP, such as [3]: (1) MRP generates infeasible solutions and this infeasibility is known too later, (2) MRP has fixed lead time. Such problems in the body of this control strategy caused the decline of MRP popularity. In eighties, Japanese industries adopted a new production control system; Just-In-Time (JIT). However, this system had some limitations like it was difficult to execute in a job shop [4]. Another control policy; CONWIP (Constant Work in Process), was developed which is hybrid of JIT and MRP driven production systems. The benefits of CONWIP over MRP and Kanban are its simple execution, flexibly to accommodate part mix, low WIP and above all robustness to error in the release rate [3]. The benefits of CONWIP production line are also verified through simulation studies [5]. Some work has been done on finding the finest junction point between pull and push system to get more benefits of the hybrid system [6]. Studies have shown comparison of CONWIP with Kanban and it has been concluded that CONWIP is easier in implementation than Kanban [7]. On contrary, some research reports the benefits of kanban over CONWIP [8], while some remained inconclusive whether other controlling systems such as JIT, TOC (theory of constraints), or other traditional methods are better [9]. There is no single control system that shows best results in all conditions. Therefore, it is advisable to diagnose and optimize the parameters of the current control strategy rather the switching the control policy [1].

In this paper, an effort is made to devise a plan: to analyze and diagnose a production line, operating under an existing control strategy, to simulate the actual production line, and to formulate a regression model for performance parameters such as WIP, Throughput and Average Cycle Time, in terms of process parameters (Inter-arrival Time, Batch size and Arrival rate). A benchmark framework is used to evaluate the production line [10].

II. METHODOLOGY

Methodology used is shown in Figure 1. According to Figure 1, the most intricate part of any improvement project is the decision where to commence. A production engineer cannot bring about any change unless he knows about the root cause of the problem. Sometimes simple engineering measure can make out the problem but if the problem cannot be

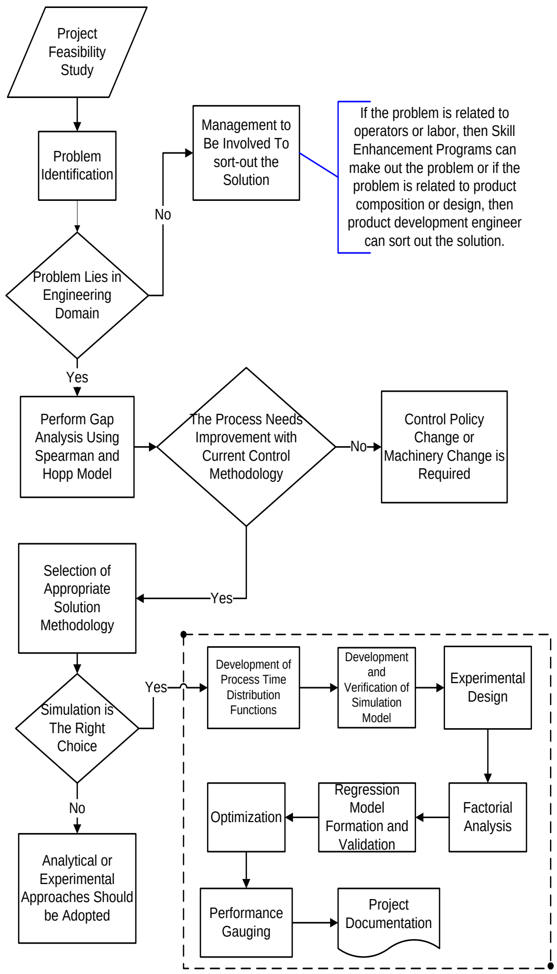


Figure 1. Research Methodology and Execution Plan

easily surfaced then some standard tools, like statistical quality control tools and Six Sigma, are used. Statistical quality control tools are simple to execute, however, if the problem is so complex then Six Sigma is applied todig out the cause. After the application of such tools, the root cause can be surfaced. The root causes can be categorized into process related issues, maintenance policy, unbalance process parameters, product composition, machine mal-functioning, operators related issues etc. Operators or labor related issues are managerial problems and can be addressed by either training the individuals or skill enhancement programs or both. Product design or composition related problems require design engineer, material engineer or chemical analyst to sort out the solution. Once the problem is surfaced, an appropriate tool is needed to perform gap analysis of the production line. The gap analysis will reveal whether there exists space for improvement or not. For gap analysis there may be a number of criterion that greatly depends on the business strategy of a company. However, internal benchmarking is the most appropriate and effortless technique [10]. Internal benchmarking provides a fundamental relationship among WIP, throughput and cycle time while covering a range of possible behaviors of a production line [10]. Since this work aims at strategy development, therefore, it is assumed that the production line under consideration has serious problem with the process parameters and needs improvement. Later, it is necessary to establish whether the current control policy is appropriate to be used and improved. In many cases only simple engineering measures can rectify the problem. However, if the dynamics of the factory is involved then simulation is the most appropriate option to capture the insight of the system with least efforts. In this paper, initially, a simulation model for a serial production line is constructed with varying input process parameters and their behavior on the output is observed.

2.1. Simulation

Simulation techniques are widely used due to their close replication of the actual systems. In this paper, a simulation model in ARENA/Simio Simulation Softwares is developed by considering a production line shown in Figure 2.

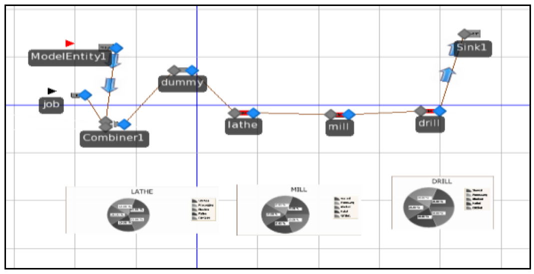


Figure 2 Simio Simulation Model for Designed Production Line

2.1.1 Developing Distribution Function for Process Time of Servers

In this case study ARENA Input Analyzer is used to fit the distributions function for the process time of the servers used in simulation Model. ARENA Input Analyzer gives various options to fit multiple distributions to the data and also provides estimates of the quality of fit [11].

2.1.2. Verification of the Simulation Model

This is the most imperative and critical phase of the simulation. The objective of verification is to see whether the designed model behaves in the same way as anticipated from it in agreement to the assumptions. In order to verify the Simulation Model, various standard verification procedures used are applied [11].

2.2 Experimental design

Experiments play central role in process design, process parameters selections, optimization and strategy selection. In order to acquire purposeful conclusions and to minimize the effect of external factors, experiments should be properly planned and designed. Therefore, to perform an experiment efficiently and scientifically, Design of Experiment Methodologies is a good choice [12].

The response variables of the experiment are the basic endeavor of the study, which are; WIP, Throughput and Average Cycle time, and the design factors are Batch size, Arrival Rate and Inter Arrival time. Factorial design methodology with no blocking is selected to formulate a well planned experiment. The details are given in Tables 1-2.

TABLE 1.

THREE FACTORS AND FOUR LEVELS DESIGN OF EXPERIMENT.

Multilevel Factorial Design	
Factors	3
Levels	4
Replications	2
Base runs	64
Total runs	128

TABLE 2.
DESCRIPTION OF THREE FACTORS AND FOUR LEVELS DESIGN OF EXPERIMENT

Levels	**Design Factors**		
	Batch (A) Size	**Arrival Rate (B) Jobs/day**	**Inter Arrival Time (C) min**
Level 1	4	36	20
Level 2	6	48	35
Level 3	8	72	45
Level 4	12	96	60

2.3 Regression Analysis

Statistical analysis techniques are very useful to draw realistic conclusions from the data. Objective conclusions can be easily framed from these graphical techniques and hypothesis testing. Researchers are mostly interested to observe the effect of their design factors on response parameters. This interplay between input and response parameters can be well explored by mathematical model obtained by regression analysis.

III. RESULTS AND DISCUSSIONS

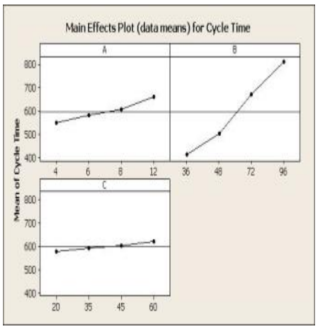
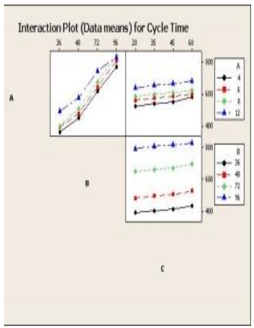
The output data from Simulation model for the designed experiment is analyzed in Minitab v15 and the results are discussed in the following paragraph:

Cycle Time Vs Factors

Main effect plot for cycle time as shown in Table 3, reveals that cycle time increase with increasing level of factors A, B and C. From joint effect plot, given in Table 3, it is clear that factors A, B and C have no interaction effect. However, with the increasing level of each factor, cycle time also increases.

TABLE 3.

FACTORIAL PLOTS FOR CYCLE TIME

	
Main Effect.	Interaction Effect Plot

ANOVA table is given in Table 4. P-value for constant term and all predictors A, B and C is less than 0.05, which shows the significance of these factors in regression equation. Moreover, R^2-value (Adj) for regression fit is 98.6%, which reveals that the quality of fit is very good. It can also be seen that there is no momentous difference between the value of R^2-value (Adj) and R^2-value, which is due to the absence of insignificant regressors [12].

TABLE 4.

ANOVA TABLE FOR CYCLE TIME

ANOVA Table for Factors

Predictor	Coef	SE Coef	T	P
Constant	34.532	7.849	4.40	0.000
A	13.6188	0.5602	24.31	0.000
B	6.66121	0.07191	92.63	0.000
C	1.0750	0.1137	9.46	0.000

S = 18.7479 R-Sq = 98.7% R-Sq(adj) = 98.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	3255019	1085006	3086.93	0.000
Residual Error	124	43584	351		
Total	127	3298603			

The regression equation

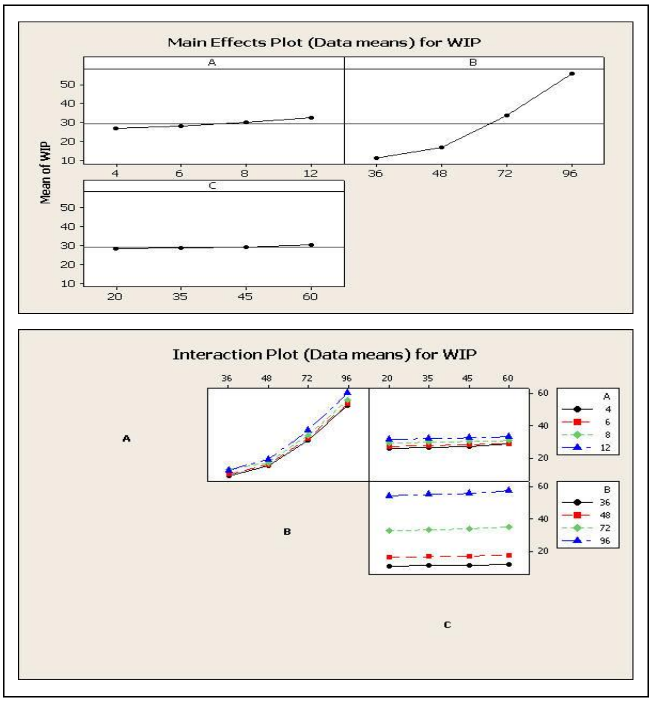
Cycle Time = 34.5 + 13.6 A + 6.66 B + 1.07 C

WIP Vs Factors

Main effect plot for WIP, shown in Table 5, reveals that WIP increase with increasing level of factor A, B and C. However, slope of curve for Factor C is very gentle, which shows that it has trivial effect on WIP. The interaction plots, shown in Table 5, illustrate no obvious interaction effects.

TABLE 5.

FACTORIAL PLOTS FOR WIP



ANOVA table is given in Table 6. P-value for constant term and all predictors A, B and C is less than 0.05, which shows the implication of these factors in regression equation. Moreover, R^2-value (Adj) for regression fit is 98.5%, which reveals that the quality of fit is very good. It can also be seen that there is no momentous difference between the value of R^2-value (Adj) and R^2-value, which enlightens the absence of irrelevant regressors [12].

Throughput Vs Factors

Main effect plot for Throughput in Table 7, shows that Throughput decreases with increasing level of factor A, However, slope of curve for factor A is very gentle, which shows that it has trivial effect on Throughput. On the other hand factor B mainly affects output of the production line and its slope is also very steep. Factor C plays an insignificant role in this case. The interaction plots, shown in Table 7, show strong interaction between factors A, B and A, C, however, there seems no apparent interaction in Factors B, C.

ANOVA table is given in Table 8. P-value for constant term and all predictors A and B is less than 0.05, which shows the importance of these factors in regression equation. P-value for factor C is greater than 0.05, which reveals its trivial effect on the regression equation. But still regression coefficient for this factor is included in the regression equation. Moreover, R^2-value (Adj) for regression fit is 98.2%, which shows that the quality of fit is very good. It can also be seen that there is no momentous difference between the value of R^2-value (Adj) and R^2-value, which enlightens the absence of irrelevant regressors [12].

TABLE 6

ANOVA TABLE FOR WIP

```
Predictor        Coef    SE Coef        T
Constant     -25.1986     0.8953   -28.14
A             0.68810    0.06391    10.77
B            0.749549   0.008203    91.37
C             0.05199    0.01297     4.01
P
0.000

S= 2.13870,R-Sq= 98.6%,R-Sq(adj)= 98.5%

Analysis of Variance

Source            DF      SS      MS
Regression         3   38790   12930
Residual Error   124     567       5
Total            127   39357
P                F
0.000            2826.82
The regression equation
WIP= - 25.2 + 0.688 A + 0.750 B
+ 0.0520 C
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TABLE 7.

FACTORIAL PLOTS FOR THROUGHPUT

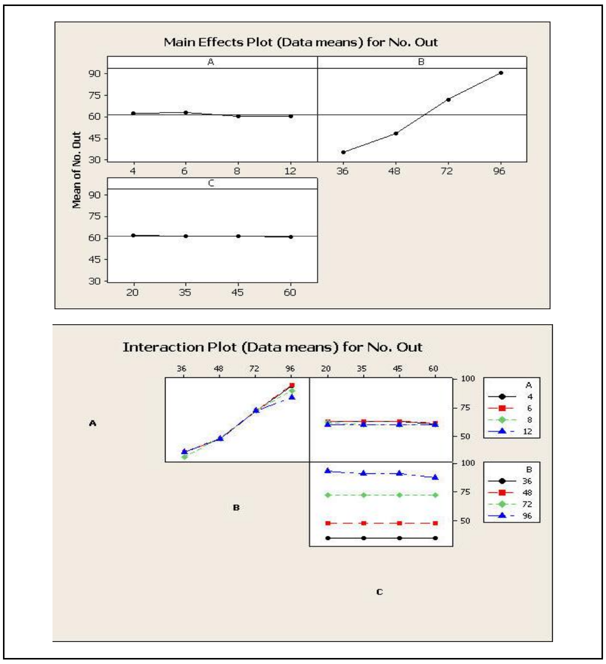


TABLE 8.

ANOVA TABLE FOR THROUGHPUT

ANOVA Table for Factors

Predictor	Coef	SE Coef	T	P
Constant	6.826	1.206	5.66	0.000
A	-0.35536	0.08605	-4.13	0.000
B	0.92920	0.01105	84.12	0.000
C	-0.03235	0.01746	-1.85	0.066

S = 2.87970 R-Sq = 98.3% R-Sq(adj) = 98.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	58855	19618	2365.72	0.000
Residual Error	124	1028	8		
Total	127	59883			

The regression equation

Throughput = 6.83 - 0.355 A + 0.929 B - 0.0324 C

Regression Model

From statistical analysis of the factors it is clear that the mathematical model developed in the previous section confirms all the statistical tests. Therefore, regression models developed on the basis of these factors are given in Table 9.

TABLE 9

MATHEMATICAL MODEL FOR WIP, THROUGHPUT AND CYCLE TIME

WIP	WIP = - 25.2 + 0.688 A + 0.750 B + 0.0520 C
Throughput	Throughput = 6.83 - 0.355 A + 0.929 B - 0.0324 C
Cycle Time	Cycle Time = 34.5 + 13.6 A + 6.66 B + 1.07 C

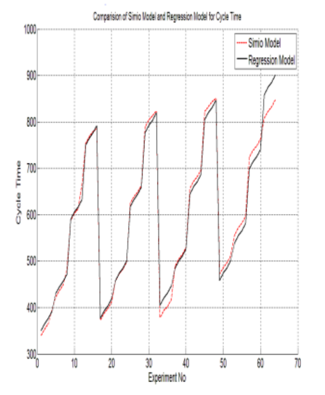
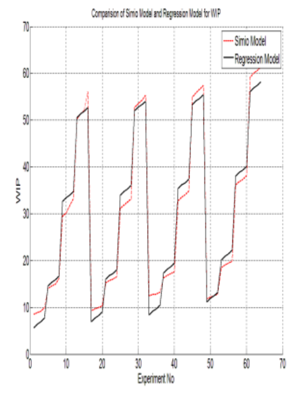
Validation of the Mathematical Model

The success of every research lies in the research methodology. A well planned research methodology gives practical results. Therefore, this work is planned in a way that verification at every stage is specially included, because errors ignored at any stage will eventually build up at higher stages and will sidetrack the direction of the research. Moreover, the validation of the mathematical model is essential to spot whether these expressions fully define the behavior of the real system or not.

In order to validate whether regression models exactly characterize the behavior of the data, performance parameters are also calculated using the mathematical expression for the same input parameters which were used in designed experiment. The results are shown in Table 10. It can be seen from these results that regression model fits well to the data. Since interaction effects, though having minor ramifications on performance, were ignored in the formulation of the regression model. Additionally, linear regression analysis is used to model these expressions which ignore the non-linearity of the data. Therefore, small fluctuations at certain points are observed in the data calculated from mathematical model.

TABLE 10.

COMPARISON OF SIMULATION MODEL DATA AND REGRESSION RESULTS.

	
Comparison of Cycle Time obtained from Simio Model and Regression Model	Comparison of WIP obtained from Simio Model and Regression Model

Furthermore, an experiment is designed to check the validity of the regression model. In this experiment Batch size is taken to be 14 units, Arrival rate is varied from 28-84 and Inter-arrival rate is kept constant at 75 minutes. This experiment is carried out on Simio Simulation Model and the output data is acquired. Performance parameters are also calculated with the same input variables using mathematical model. Graphical comparison of the data obtained from Simio Simulation Model and Mathematical Model is shown in the Figure 3 to5. It is evident from these figures that the simulation results and those obtained from mathematical model follows the same trend. From Figure 4, it can be seen that WIP level obtained from simulation model shows some fluctuation while the results from Mathematical model gives linear response. This is because in this study Multi-factor linear regression model is used which does not capture the non-linearity of the data. However, it can be concluded from discussions, statistical analysis and graphical comparison that the regression model developed predicts the behavior of the system.

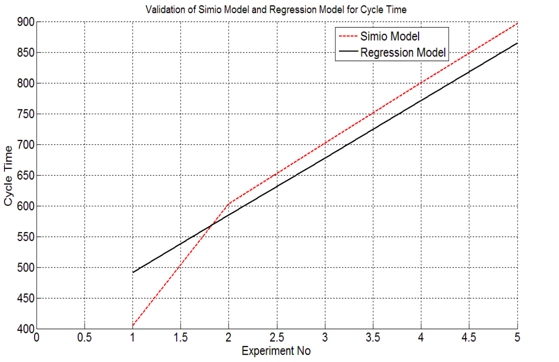


Figure 3 Validation Experiment for Cycle time: Simio Model Vs Regression Model

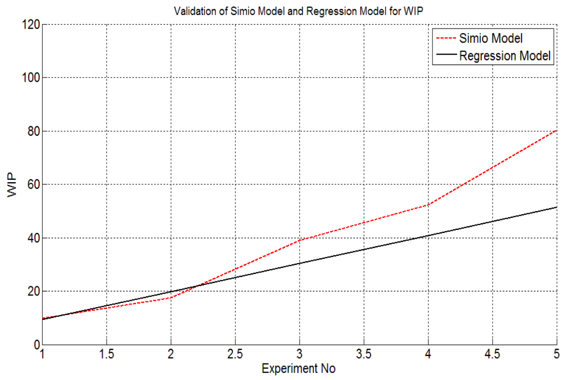


Figure 4 Validation Experiment for WIP: Simio Model Vs Regression Model

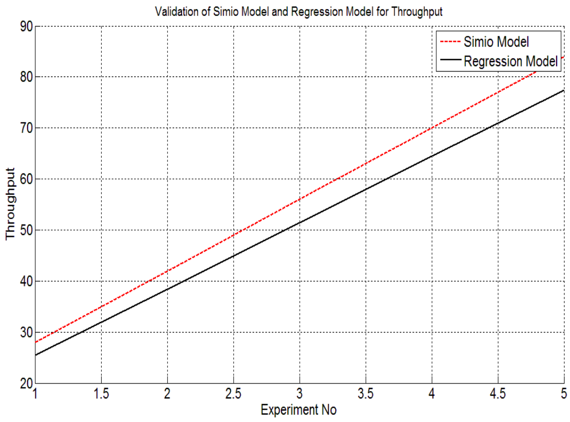


Figure 5 Validation Experiment for Throughput: Simio Model Vs Regression Model

IV. Conclusions

This research focused on devising a methodology to diagnose a production line to analyze the gaps and to assist an engineer to arrive at a reasonable solution. A simulation model of an MRP driven serial production line is developed under varying input parameters to check the behavior of the line. Three factors (batch size, arrival rate, and inter arrival time with four levels are considered. Response variables (Throughput, WIP, and average Cycle Time) from the simulation model are statistically analyzed. ANOVA is performed to check the importance of the factors in the regression equation. P-value for constant terms and all predictors A and B is less than 0.05, which shows the importance of these factors in regression equation. P-value for factor C is greater than 0.05, which reveals its trivial effect on the regression equation. R^2-value (Adj) for regression fit is quite good (98.2%) which shows that the quality of fit is also good. Regression models can help assist to predict the output of the real system.

ECOMMENDATIONS

In this research work, multi-factors multi-levels linear regression analysis with no interaction effect is performed in Minitab v15. The up-shot of this type of analysis is that it excludes the joint effect and non-linearity of the data. If there is non-linearity in the data or if there is cyclic behavior of the data, an equation developed from two levels of each factor will not be able to characterize the behavior of the system. Therefore, a dedicated code should be developed for multi-factors, multi-levels non-linear regression analysis with interaction effects.

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