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Analysis of Lead Time Delays in Supply Chain: A Case Study

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Abstract**—**Lead time is a critical measure of a supply chain's performance. It impacts both the customer satisfactions as well as the total cost of inventory. This paper presents the result of a study on the analysis of the customer order lead-time for a multinational company. In the study, the lead time was divided into three stages respectively: order entry, order fulfillment, and order delivery.

A sample of size 2,425 order lines was extracted from the company's records to use for this study. The sample data entails information regarding customer orders from the time of order entry until order delivery. Data regarding the lead time of each stage for different orders were also provided. Summary statistics on lead time data reveals that about 30% of the orders were delivered later than the scheduled due date. The result of the multiple linear regression analysis technique revealed that component type, logistics parameter, order size and the customer type have significant impacts on lead time. Data analysis on the stages of lead time indicates that stage 2 consumed over 50% of the lead time. Pareto analysis was made to study the reasons for the customer order delay in each stage. Recommendation was given to resolve the problem.

Keywords**—**Lead time reduction, customer satisfaction, service quality, statistical analysis.

I. Introduction

THE companies measured their performance in terms of customer related measures such as customer satisfaction, customer retention, and service lead time usually referred to as customer focused. Having a customer focus is usually a strong contributor to the overall success of a business organization and leads to a strong relationship with customers. In supply chain management literature, shorter lead time leads to a more responsive supply chain that has higher percentage of on time deliveries and more satisfied customers and less cost of inventory [1].

Reference [2] defined lead time as the time measured from the moment the customer sends a purchase order until the customer receives the order. In this lead process can be divided into three stages**:** order entry, order fulfillment, and order delivery to the customer.

This study aims to analyze the customer order lead time data of a multinational company that sells electrical equipment to several countries of the world to identify the variables having significant impact on the lead time variability. It also examines the lead time stages to determine the stages having the strongest contribution to lead time delays. Pareto analysis is employed to identify the vital few causes for the lead time delays and recommendations to resolve the problem are presented. The control chart for attributes (P-Chart) is also employed to determine the proportion of orders that were delivered after the scheduled due dates.

II. Literature Review

Reference [3] presented a 5-step procedure to determine the lead time scheduling of operations of orders. It showed that the accuracy of the lead time scheduling is dependent upon the estimation of the order operating time accuracy. In a working paper by [4], the author divided the lead time into five phases and presented a case study to perform a bi-criteria classification for customers by size and loyalty. In addition, the author provided distribution analysis of the lead time delay at customer level, the determination of delay probability distribution function and the estimation of the mean delay time.

Reference [5] proposed an analytical procedure to solve the problem of determining the optimal production planning lead-time design in the case when the production system is serial and having stochastic processing time. References [6], [7] have extended the results presented in [3] to encompass the cases when a two level distribution system is considered as well as two level assembly system. Reference [8] proposed a model to resolve the problem of determining the optimal production planning lead-time design problem when the production system is serial and the time is stochastic. The authors were unable to extend the results to a complex system due to the model difficulty. Reference [9] presented a procedure to determine the lead time of a stochastic production system.

Reference [10] presented an article to review the lead time reduction techniques. Several authors were reviewed whom proposed techniques to reduce lead time at an added crashing cost which are cost of operation, cost of transportation, and cost of production. The added cost may include extra costs for fast transaction, employee overtime costs, extra cost for fast delivery and equipment costs.

Reference [11] has investigated the relationship between price, lead time, and delay in steel manufacturer in Indonesia. The author used the theory of purchasing and business buyer behavior and some quantitative techniques to investigate the

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problem. The model independent variables are price, lead time and delay while the dependent variable is the order quantity. They considered 42 incoming shipments from 2009 to 2012. The study revealed that the only independent variable that was identified to have significant relationship with order quantity is the price.

III. Problem Statement

The research problem is to study the customer order lead time data for a multinational company that sells electrical equipment to several countries of the world. The company products were classified using the ABC_FMR classification approach which is referred to as the logistic parameters. The ABC classification approach classifies products into three categories [2]: class A items consists of the products having the strongest level of control and high record accuracy; class B items consists of the products having medium level of control and average record accuracy; class C items consists of the ones with the weakest level of control and minimal record accuracy. The logistic parameters ABC_FMR classification divided products into 9 categories as shown in Table I.

TABLE I
ABC_FMR Matrix

	F High Frequency	M Medium Frequency	R Low Frequency
A High Value	AF	AM	AR
B Medium Value	BF	BM	BR
C Low Value	CF	CM	CR

According to the company management, the products that are labeled AF, AM, BF, and BM are fast moving with expensive prices that are made to stock; while products BR, CF, CM and CR are made to order. The fast moving products (F) are the ones with frequency more than 10; while the products with frequency less than 4 are classified as (R) slow moving. The other components are classified as (M) medium frequency. The percentages of products in each class are presented in Table II. Class G_1 is the one representing all categories of A items. The percentage of the G_1 items sold is about 20% of all the items sold. The company target lead time for this class of 30 days. This also makes about 85% of the sales.

The aim of this study is to analyze the customer order lead time data, identify the factors impacting lead time and proposing solutions to the lead time problem.

This process can be divided into three stages**:** order entry, order fulfillment, and order delivery to the customer. In the order entry stage, the customer sends a purchase order (PO) either through e-mail or through the Digitized Tool which is a customized system made by the company to help the customers place their order online. The Digitized Tool will then examine the customer credit limit; will check the requested product to see if already created on the company system, and ensure the order is complete. In case of any existing problem with the customer order, this conflict must be resolved before the order is registered by the customer care agent. The order fulfillment stage is the one when the company will process the order and send it to a supplier to provide the company with the required materials. The third stage starts from the moment the order arrives to the company's warehouse until the time the order is delivered to the customer.

TABLE II
New Lead Time Offer and Stock Holding Ownership

	% Items	% Sales	Targeted Lead time offer (Days)
G1	20%	85%	30
G2	26%	11%	15
G3	54%	4%	60

The aim of this study is to use extracted lead time data from company information systems such as ERP and the Digitized tool in order to identify the factors that significantly impact lead time and provide solutions for lead time reduction. The data analysis will identify the lead time stage having the strongest impact on lead time variable, the stage that contribute the most to lead time variability and the suppliers contributing the most to lead time variability. The control chart for attribute (P-Chart) will be employed to determine the proportion of orders delivered after the scheduled due date.

IV. Lead Time Data Analysis

This section presents statistical analysis of the customer order lead time data. An extended Excel document entailing data in regards to order numbers, order entry times, scheduled order delivery times, actual delivery times, order sizes, logistic parameters, and customer classes was considered for this study. In addition, the number of days each order was overdue in regards to its scheduled due date was determined and a binary variable was added to the Excel sheet having a value of 1 corresponding to the order that was delivered late and 0 corresponding to the order that was delivered on time.

A. Summarizing the Lead Time Data

This section presents summary of the statistical lead time data. A sample of 2425 observations was considered to estimate the population average, median, quartiles, standard deviation, skewness, and the coefficient of variation (CV) for the lead time population.

Table III shows that the sample mean lead time is about 26 days and the median is 20 days. Results also reveal that about 25% of the customer orders were delivered in less than or equal to 12 days, 50% were delivered in less than or equal to 20 days, and 75% of the orders were delivered in less than or equal to 32 days. The remaining 25% of the orders took from 32 days to a maximum lead time of 145 days. The table also shows that the lead time standard deviation is 21.4 days which is a large number, indicating that the values of the lead times were not consistent and that they had much variability.

Considering only the orders that were delivered after their scheduled due date, this study reveals that their average late time is 12.9 days. This study shows that the average proportion of late delivery of customer order was 0.302, indicating that about 70% of the orders was delivered on time.

TABLE III
STATISTICAL SUMMARY OF CUSTOMER DEMAND LEAD TIMES

Descriptive Measure	Lead Time Descriptive Measures (Days)
Mean	25.9 Days
Standard Deviation	21.4 days
Coefficient of Variations	82.5%
Skewness	1.58
Median	20 Days
Quartiles-First	12 Days
Second	20 Days
Third	32 Days
Percentage of Late Orders	30.2%

B. Regression Analysis

The multiple linear regression technique is employed in this section to determine the variables impacting the lead time of customer demand. The stepwise regression analysis technique was implemented [12]. In his approach, several independent variables were introduced to the regression model, the variables of which proved their significance relationships remind in the model while those that were insignificant were removed from the regression model. After trying all possible independent variables, the variables that had a significant relationship with the lead time were the order size, logistics code, product category, and customer class. The regression model representing the population is stated as:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon \qquad (1)$$

The model requires that both the independent and dependent variables to be *interval data*. In this case, the lead time (Y) is the model dependent variable that can be measured in days and it is classified as interval data. The customer demand is a model independent variable and can be measured in units of products. This variable is also classified as interval data. The logistics parameter, product type and the customer class are classified as nominal data. The nominal data are not numerical data and they have to be represented somehow by dummy variables having binary values.

Logistics parameter, for example, has several categories, the categories that passed the significance test are G_1, G_2, G_3, G_4, G_{51}, where G_1indicates fast moving and expensive product. This logistics code is represented by some *indicator variables* or *dummy variable* [13]. The indicator variables representing the product class are explained as:

$$G_i = \begin{matrix} 1\ if\ the\ item\ belongs\ to\ class\ G_i \\ 0\ if\ the\ product\ does\ not\ belong\ to\ that\ class \end{matrix}$$

where, $i = 1, 2, 3, 4, 51$. The other categories of logistics parameters are represented by $G_1 = 0$, $G_2 = 0$, $G_3 = 0$, $G_4 = 0$, $G_{51} = 0$. Similarly, the product type has several categories. The categories that are proven to be significant were: A02, A03, A11, A22, A23, A24, A26, B10, and B13. One categories of the customer type (End User) was found to impact the lead time. The variable ε in (1) is *a random variable* referred to the *error variable*. For the linear regression to be valid, the probability of the error variable has to satisfy the following conditions [13]:

1. The variable must be normally distribution with mean of 0.
2. Constant standard deviation regardless of the values of the independent variables.
3. The errors are independent.

The regression model coefficient $\beta_i, i = 0, 1, 2, \ldots, n$ and $n = 16$ independent variables in the regression model are population parameters and their estimates are determined from the sample data. The regression analysis technique uses the empirical data to determine unbiased estimates to the population coefficients. Those estimates are shown in (2), where $b_i = \widehat{\beta_i}, i = 0, 2, \ldots, n$, i.e. b_i is the estimate of β_i. Also $\hat{y}$ is an estimate of Y. Therefore, statistical tests will be conducted to test the validity of those coefficients. The estimated regression equation is:

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n + \varepsilon \qquad (2)$$

The following is the estimated regression equation from the data set:

$$\hat{y} = 38.5 + 0.0018Q + 11.05A_{02} + 8.49A_{03} + 16.49A_{11} - 4.8A_{22} - 16.5A_{23} + 10.04A_{24} + 16.49A_{11} - 4.8A_{22} - 16.5A_{23} + 10.04A_{24} - 10.26A_{26} + 3.8B_{10} - 27.3B_{13} - 18.37\,G_1 - 18.26\,G_2 + 5.79G_3 + 11.19G_4 - 7.16G_{51} + 20.65SI \qquad (3)$$

The result of the regression analysis revealed that if a customer order does not include: the identified logistic parameters, the identified product categories, and the customer class SI-System, the average lead time will be 38.5 days. If the order size increases, the lead time will increase 18 days for each 10,000 items increase. When a customer orders products such as: $A_{02}, A_{03,} A_{11}, A_{24}, B_{10}$ the order lead time will increase by 11, 8.5, 16.5, 10, 3.8 days respectively on the average. However, if the customer orders products such as: A_{22}, A_{23}, A_{26}, B_{13} the lead time of the order will decrease by 4.8, 16.5, 10.3, 27.3 days respectively on the average. If a customer from the SI-System class places an order, the lead time is expected to increase by 20.6 days.

The coefficient of determination (adjusted R-square) is 25.3% and that indicates only 25.3% of the lead time variations can be explained by the independent variables described above, while the remaining 74.4% are due to examined factors.

The following hypothesis tests the validity of the regression model:

$$H_0: \beta_1 = \beta_2 = \cdots = \beta_n = 0$$
$$H_1: At\ least\ one\ \beta_j\ is\ not\ equal\ to\ 0$$

The null hypothesis of the test is rejected since the significance F shown in Table IX (in the appendix) is almost 0. Therefore at least one coefficient of the regression equation is not 0. This affirms that there is a great deal of evidence inferring the validity of the regression model.

The following hypothesis will test the value of the y-intercept to see whether it is 0 or not when all the independent variables have values of 0.

$$H_0: \beta_0 = 0$$
$$H_1: \beta_0 \neq 0$$

The P-value corresponding to this coefficient in the regression output (Table IX) is 1.56E-88 which is almost 0. Therefore, the null hypothesis is rejected. Therefore, there is a great deal of evidence that the y-intercept of the regression equation is not 0. Similarly, each regression coefficient $\beta_i, i = 1, 2, \ldots, n$ is tested as:

$$H_0: \beta_i = 0$$
$$\neq 0$$

There are great deal of evidences inferring that the coefficients of all independent variables are not 0, since all the corresponding p-Values are close to zeros.

V. Analysis of the Lead Time Stages

The lead time of customer orders are divided into 3 stages: customer order entry, order fulfillment, and customer order delivery. Order entry stage starts from the time the customer places an order online until customer care agent registers the order and sends it to purchasing for processing. The second stage starts from the moment the order is received by purchasing until the time the order becomes available in the company warehouse. The last stage starts from the time of order arrivals to company warehouse to the time when it is actually delivered to the customers. Table IV shows the summary statistics of a sample of size 1781 observations for the lead time stages.

Statistical analysis results reveal that lead time averages for stages 1, 2, and 3 are 2, 15, and 10 days respectively. Stage 2 consumes 55.5% of the total lead time, stage 3 consumes 37% and stage 1 only consumes 7.5%. For over 50% of the customer orders, the time of stage 1 is zero; 75% of them is more than or equal to 2 days. The most inconsistent part of the lead time is due to Stages 2, and 3. Their values in the period when the sample was collected reached to 136 and 86 days respectively.

TABLE IV
Statistical Summary of Lead Time Stages

Descriptive Measures		Lead Time Stages (Days)		
		Stage 1	Stage 2	Stage 3
Mean		2	15	10
Percentage		7.5%	55.5%	37%
Standard Deviation		2.66	17.88	10.38
Quartiles	Q1	0	2	4
	Q2	0	8	6
	Q3	2	20	12
Min		0	0	0
Max		14	136	86

Pareto analysis technique was employed to investigate the quality problems that contribute to the lead time variability. A study was made to investigate the causes of lead time delay. Table V reveals the causes for stage 1 delay:

TABLE V
Pareto analysis data – Stage 1

Reasons for Lead Time Delay	Percent Frequency
Customer pay for their orders using their company checks which require long time to clear. They delay may take from 8-14 days	45%
Agent delay. It takes from 3-4 days.	39%
Delay due to technical issues	15%
Other reasons	1%

Table V identifies two vital causes for lead time delay. The first is the delay occurs for the orders paid by customer checks. This problem can be resolved if a policy was made to only accept cashier checks rather than customer checks. The other recommendation is that the company may consider facilitating payment terms to the customers. Those recommendations may decrease lead time for the first stage. The second cause requires an increasingly restricted management control to ensure that an order is registered immediately when it is ready.

TABLE VI
Pareto Analysis Data – Stage 2

Reasons for Lead Time Delay	Frequency
Supplier delivered the order late to the company warehouse	62%
Order arrived on time to the company warehouse but company agent has created delivery document late	10%
Purchasing placed their replenishment order late from the supplier	10%
3rd Party logistic provider delivered the order late to company warehouse	18%

The result of this research indicated that stage 2 is the vital stage in lead time reduction. It impacts about 55% of the total lead time. Pareto analysis reveals that the vital problem leading to the most lead time variability in stage 2 is the supplier delay. This issue is attributed mostly to the company suppliers. The company management should use the supplier historical delivery data in their supplier evaluation process. The inconsistency of suppliers in their delivery time should be reevaluated and possibly even removed from the company list of suppliers.

TABLE VII
Pareto Analysis Data – Stage 3

Reasons for Lead Time Delay	Frequency
Order arrives on time to company, but the company agent has created delivery document late	40%
3rd party logistic took much time to deliver products to customer	50%
Other reasons	10%

The Pareto analysis study in Table VII identifies the causes for the lead time delay in stage 3. The study reveals two vital reasons for the delay in this stage: the delay due to the 3rd party logistics company and the delay due to the company agent. Evaluation should be made to the third party logistics providers as well as more tight management control may help to resolve those problems in this stage.

VI. Analysis of the Proportion of Delayed Orders

This section presents the control chart for the proportion of times in which order was delivered after the scheduled due date. The control chart for attribute (P-chart) is employed to monitor the proportion of orders that were delivered after the scheduled due date over time.

We considered 24 samples of size 100 observations each. The proportions of late order deliveries are shown in Table VII for each sample. The average proportion of late deliveries and the standard deviation were found to be:

$$\bar{p} = 0.302$$

$$\hat{\sigma}_p = \sqrt{\frac{\bar{p}\,(1-\bar{p})}{n}} = 0.04591$$

The upper and lower control limits were computed as:

$$UCL = 0.302 + 3(0.04591) = 0.4397$$
$$LCL = 0.302 - 3(0.04591) = 0.1643$$

Fig. 1 illustrates that there are 11 samples out the 24 samples considered in this study are outside the control limits and this suggests that an immediate action must be taken to restore the system lead times.

IV. Conclusion

This case study presents statistical analysis to customer order lead time in a multinational company. Regression analysis results illustrate that logistics parameters, product type, customer type and order size has significant impacts on lead time. Thorough studies of the different stages of lead time revealed that stage 2 is the longest and most effective stage that should be considered in lead time reductions. Check clearance time was found to be the main reason for the delay in stage 1. It was recommended to use of cashier checks to reduce the check clearance time. It was recommended to re-valuate the suppliers and consider the removal of the suppliers that are not consistent in their delivery times from the supplier list. It was also recommended to re-evaluate the company 3rd party logistics providers. Research results also request tight management control to insure that orders were registered on time and replenishment orders were made on time.

TABLE VIII
Proportions of Late Deliveries

Sample	Proportion	Sample	Proportion
1	0.67	13	0.13
2	0.74	14	0.27
3	0.39	15	0.59
4	0.18	16	0.38
5	0.04	17	0.23
6	0.42	18	0.8
7	0.13	19	0.17
8	0.35	20	0.26
9	0.18	21	0.31
10	0.06	22	0.60
11	0.11	23	0.21
12	0.12	24	0.24

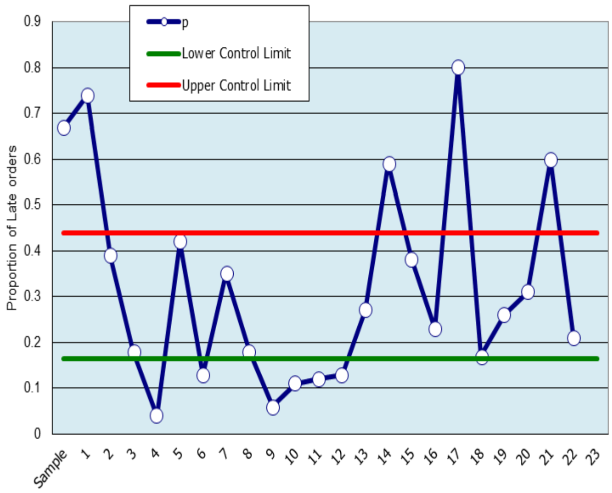

Fig. 1 Proportion of Late Orders (P-Chart)

APPENDIX

TABLE IX
REGRESSION ANALYSIS OUTPUT FROM THE EXCEL ADD INS DATA ANALYSIS

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.508109
R Square	0.258175
Adjusted R Square	0.253245
Standard Error	18.49305
Observations	2425

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F*
Regression	16	286606	17912.88	52.37791	4E-143
Residual	2408	823519.1	341.993		
Total	2424	1110125			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	38.50189	1.850746	20.80344	1.56E-88	34.87267	42.13111
QTY	0.001798	0.000233	7.701983	1.94E-14	0.00134	0.002256
A02	11.04962	1.261333	8.760272	3.6E-18	8.576209	13.52303
A03	8.49237	1.177249	7.213742	7.26E-13	6.183844	10.8009
A26	-10.26	1.314718	-7.80392	8.87E-15	-12.8381	-7.68186
B10	3.807047	1.430452	2.66143	0.007833	1.002003	6.61209
G1	-18.372	1.954014	-9.40218	1.2E-20	-22.2037	-14.5403
G2	-18.2673	1.957791	-9.33059	2.31E-20	-22.1065	-14.4282
G3	5.792448	2.248306	2.576362	0.010044	1.383634	10.20126
G4	11.18998	5.370406	2.083638	0.037298	0.658888	21.72108
G51	-7.10618	2.529598	-2.80921	0.005006	-12.0666	-2.14576
SI-System	20.65373	4.283077	4.82217	1.51E-06	12.25483	29.05262
A11	16.49125	4.989819	3.30498	0.000964	6.70647	26.27604
a22	-4.81353	2.189349	-2.19861	0.028	-9.10673	-0.52032
a23	-16.5171	7.05881	-2.33993	0.019368	-30.3591	-2.67517
a24	10.04136	3.904616	2.571663	0.010181	2.384603	17.69811
b13	-27.3274	5.428328	-5.03422	5.15E-07	-37.9721	-16.6827

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