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Abstract

In the electro-mechanics industry, the manufacturing is performed by project type production and most of the sales are performed by tender offers. Because of project based manufacturing, the most of the transformers are produced for the first time and the processing times for these orders are unknown. In this case it is important to estimate the cost of the customer order before the production at a bidding stage for accurate price offer and win the tender. In this labor-intensive sector; accurate estimation of the labor cost has great importance to give a realistic price offer. Therefore, it is important to estimate the flow time and due date with a low variance. In this study, the core production process of a transformer company is simulated by using Arena software, and the technical specifications indicated in the customer orders are used as simulation inputs for the transformers to be produced for the first time.

Keywords: Due date, Flow shop, Flow time, Simulation, Transformer.

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Introduction

In the electromagnetics sector transformers are produced by a labor intensive project type production system. Except from a few similar transformers produced frequently; there are unlimited types of different transformer orders which vary according to the customer specifications those will be produced the first time. This variation causes different processing times, a flow time (FT) and due date (DD) for each type of order which has to be predicted before starting the production.

There are so many studies presented in the literature that estimate the processing time, FT, and DD by using simulation models, probability distributions and other statistical techniques and presented remarkable results. Ekren and Ornek (2008) presented a simulation based experimental design to analyze factors affecting the production flow time. Baykasoglu and Gokcen (2009) proposed a new approach that is based on a genetic programming technique which is known as a gene expression programming (GEP), and compared the performance of the proposed due date assignment model with several previously proposed conventional due date assignment models. For this purpose, simulation models are developed and comparisons of the due date assignment models are made. Slomp et al. (2011) studied on estimation of flow times of jobs to be produced in a flexible manufacturing cell (FMC) consisting of a number of identical machines by the aid of simulation. Joseph and Sridharan (2011) investigated the effects of dynamic due-date assignment models (DDDAMs), routing the flexibility levels (RFLs), sequencing flexibility levels (SFLs) and part sequencing rules (PSRs) on the performance of a flexible manufacturing system (FMS) for the situation wherein part types to be produced in the system arrive continuously in a random manner. They used a discrete-event simulation model of the FMS as a test-bed for experimentation. Vinod and Sridharan (2011) also presented the salient aspects of a simulation study conducted to investigate the interaction between due-date assignment methods and scheduling rules in a typical dynamic job shop production system. Simulation experiments are carried out for the different scenarios that arise out of the combination of due-date assignment methods and scheduling rules. They found that dynamic due-date assignment methods provide better performance and they developed regression-based metamodels using the simulation results. Azaron et al. (2011) concerned with the study of the constant due-date assignment policy in repetitive projects, where the activity durations are exponentially distributed random variables and they verified the results by Monte Carlo simulation. Akinnuli et al. (2012) developed a computer-aided system which is based on a simulation and empirical model for predicting job-shop FT and DD. Thurer et al. (2012) evaluated the performance of DD setting rules in the context of complex product structures by using simulation. In the following year Thurer et al.

(2013) compared the performances of 11 different DD Setting Rules in Job Shops with Contingent Orders by the aid of simulation.

Hsieh et al. (2014) proposed a methodology, called progressive simulation metamodeling (PSM). They used a response surface methodology based simulation. Lee (2014) consider a problem of estimating order flow times in two-stage hybrid flow shops, where orders arrive dynamically and various scheduling schemes can be used. In this study several order flow time estimation methods are devised and actual flow times of orders are obtained from simulation runs. Li et al (2016) developed a simulation-based statistical approach. They provided responsive and high-quality prediction of a new job's FT through the system, which renders the capability of accurately quoting lead times in real time. In this approach they integrated an analytical queuing analysis, design of experiments, and statistical modeling to quantify the dependence of a new job's FT distribution upon the shop status.

In the literature the common practice to predict the FT is using general job and shop characteristics such as the number of the job in the queue, processing times, number of resources, dispatching rules and etc. In addition, it is assumed that the processing times or its probability distribution are known before starting the production. However, this assumption is not valid for transformer production. In this case study, the processing times or its probability distribution is not known for the orders which will be produced the first time. This causes problems at giving accurate price offers to the customers because of unknown processing times and FT of unlimited kind of orders.

In the transformer production, the processing times of operations, the FT and the DDs of each order vary according to the technical specifications that are demanded by the customer. In this study, these parameters for each order is predicted by using an interface software developed by the authors (which is based on Arena simulation model, statistical modeling and probability distributions) with the consideration of the technical data instead of using the general job and shop characteristics. The following section gives a brief description of the materials and methods used in this study. The case study, simulation results and the interface software developed for the BEST Transformers Co. are presented in the "Arena Simulation" section. Finally, the conclusions are given in the last section.

Materials and Methods

The transformers production process has five main stages: core production, winding operations, mechanical production, assembly, and final assembly. In this study, simulation based interface software is developed for estimating the processing times, FT and DD of the core production process of the transformers to be produced at the first time. This interface software will be used by the company to provide data to the sales staff at the bidding stage to calculate the labor hours, labor cost and prepare better price offering. Also, the outcomes of this software will be used for the scheduling of core production of BEST Transformers Co.

To develop this interface software, the Arena simulation model is created for the core production of the company. Then, the processing times of labor intensive processes and preparation times are modeled by using probability distributions while the standard machining processes are modeled by mathematical models of design of experiment (DOE) techniques. To run this simulation a user-friendly interface is coded by using Visual Studio software. By using this interface, the user enters the technical design parameters to the program and obtains the simulation results.

Arena Simulation

Simulation is a powerful tool to find good solutions in stochastic environments. Rosetti (2010) defined the simulation as "a numerical technique for conducting experiments on a digital computer which involves logical and mathematical relationships that interact to describe the behavior of a system over time". Nowadays, simulation is often used in various fields and industries by computational power and storage capacity of contemporary computers and software which are better than ever.

There are many competing languages to conduct a simulation work in a computer. Some of these languages are specially created for simulation and uses drag and drop modules like Arena, Promodel, etc. Arena is one of the most popular simulation software and has input and output analyzer modules. Moreover, it exploits ActiveX Automation and Visual Basic for Applications (VBA) for integrating directly with other programs. In this paper, Arena 14 simulation software is used for the simulation.

Response Surface Methodology (RSM)

The design of experiment (DOE) techniques are used for modeling the relationship between the input variables (factors) and the output variable (response) by using the minimum number of experimental results. By this way it is possible to optimize the system parameters or to predict the response of unpracticed combinations of different factor levels. This requires less time and effort. The well-known DOE techniques are response surface methodology (RSM), factorial design and Taguchi. RSM provides the mathematical relations including interactions between the factors besides the linear and quadratic relations. Equation (1) shows the general second-order polynomial RSM model for the experimental design (Montgomery, 2001).

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i<j}^{n} \beta_{ij} X_i X_j + \varepsilon \quad (1)$$

where Y is the response, X_i and X_j are the factors, terms, β_0, β_i, β_{ii} and β_{ij} are the regression coefficients, and ε is the residual. Equation (1) may be written in matrix notation as:

$$Y = \beta X + \varepsilon \quad (2)$$

In this equation, Y and X represents the output and input matrices respectively. The residual terms are given by the matrix represented with ε. The least square estimator of the β matrix that composes of coefficients of the regression equation (β_0, β_i, β_{ii} and β_{ij}) calculated by the given formula in Equation (3), by ignoring ε;

$$\beta = \left(X^T X\right)^{-1}\left(X^T Y\right) \quad (3)$$

where X^T is the transpose of X.

Probability Distributions

The widely used probability distributions in the Arena are Uniform, Normal, Exponential, Erlang, Gamma, Weibull, Lognormal, Beta, and Triangular. In this study Erlang, Beta and Triangular distributions best fit the processing times of labor intensive processes and preparation processes (Rosetti, 2010). The common modeling situation for Triangular (*a*,*m*,*b*) distribution assumes a minimum, a maximum and a most likely value. Also, this distribution roughs model in the absence of data. The probability density function (*F(x)*) of Triangular distribution is given in Equation (4-5):

$$\frac{\left(x-a\right)^2}{\left(b-a\right)\left(b-m\right)} \qquad a \le x \le m \quad (4)$$

$$1-\frac{\left(b-x\right)^2}{\left(b-a\right)\left(b-m\right)} \qquad m \le x \le b \quad (5)$$

Where a, b, and m are the minimum, maximum and mode respectively. The common modeling situation for Erlang distribution is multiple phases of service with each phase exponential. The probability density function of Erlang (θ, r) distribution is given in Equation (6):

$$1-\sum_{n=0}^{r-1}\frac{e^{-x/\theta}\left(x/\theta\right)^n}{n!} \quad (6)$$

Where θ is the mean of each of the component exponential distributions, and r is the number of exponential random variables. Beta distribution is useful for modeling task times in a bounded range with little data. The probability density function of Beta (α_1, α_2) is given in Equation (7-8):

$$\frac{x^{\beta-1}(1-x)^{\alpha-1}}{\beta(\beta,\alpha)} \quad 0<x<1 \tag{7}$$

Where β is the complete Beta function given by:

$$\beta(\beta,\alpha)=\int_0^1 t^{\beta-1}(1-t)^{\alpha-1}\,dt \tag{8}$$

Shape parameters Beta (β) and Alpha (α) specified as positive real numbers.

The Case Study

BEST Transformers is a transformer producer and produces power transformers, distribution transformers and dry-type transformers. This study is performed at a core production of distribution transformers. In this production oil type and dry type cast resin transformers are produced by flexible flow shop that is composed of consequent processes. The main production steps are core production, winding operations, mechanical production, assembly, and final assembly. The coils produced by separate winding operations are assembled with the core. Then this mid-product is put in the tank which is produced by mechanical production. Then, the final operations are performed on this mid-product and the production is finalized. This study is motivated on core production of oil type transformers.

In this production system, actually each of the received transformer order can be accepted as a new product. The same transformers' designs with equal power and voltage numbers may be completely different because of technical specification those are demanded by the customers. These design differences engage accurate prediction of processing times, FT and DD of the orders those will be produced at first time.

In this study FT estimation of received transformer orders are performed by using the mathematical equations of RSM, probability distributions and Arena simulation. RSM was employed by using Minitab program, while probability distributions and simulation were employed by using Arena simulation software. In the proposed approach if the probability distribution for processing time of the product has been defined, it is used at the simulation. Otherwise, processing times of the products which are produced at the first time are estimated by regression equations developed according to the product technical specifications.

The core production is mainly composed of slicing, cutting and stacking operations. In slicing operation, steel slice stocks are primarily checked and ones which are not in stock are sliced in slice cutting machine from the roll in width set design. In cutting operation, sliced rolls are cut in measurements determined in design criteria and prepared for stacking operation. Stacking operation is labor-intensive and the sheets cut are stacked in stacking tools by workers. In addition, some parts used in stacking operations are produced in carpenter. The results of the analyzes performed show that carpenter, preparation and the final completion times don't change slightly according to technical characteristics, therefore probability distributions determined by the Arena input analyzer software are used for these processing times. The goodness of fit of the distributions is tested by the Chi-square test in 0.05 significance level, and the results show that determined probability distributions can be used in the simulation. Cutting times are sensitive to technical specifications according to the result of the analysis. Therefore, a mathematical equation for cutting times is developed by RSM, and cutting times generated from mathematical equations are used in the simulation. The probability distributions and mathematical model used in the simulation are given at Table 1 in terms of minutes. Transfer distances in the factory among work stations and stock fields are measured and transfer times of material/ product are determined for the simulation by entering the speed of used transporters.

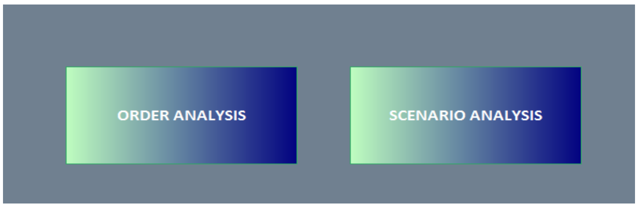
Table 1. *Processing Time Models in the Simulation*

Operation	**Model**
Carpenter Time	10+120*Beta (0.751, 1.31)
Tap Slice Time	(20+119*Beta(1.44,1.5))
Cutting Time (x_1: *weight*, x_2: *number of sheet*)	$0.0495443-5.16233*x_1+62.8709*x_2-143.455*x_1*x_1-81.0161*x_2*x_2 + 230.667*x_1*x_2$
Preparation Time for Tap Cutting	Triangular (8, 11, 14)
Completion Time for Cutting	Triangular (23, 29, 35)
Preparation Time for Stacking	Triangular (32, 49, 61)
Limb Stacking Time	(6+Erlang(3.69, 2)
Completion Time for Stacking	Triangular (30, 40, 50)

The simulation model firstly reads the production order records pending to be produced from an excel file and simulates these orders by taking in to account the dynamics conditions of the workshop. The orders whose required processing time and DD need to be calculated are added current orders records and simulated.

The created simulation model will be used by both the sales and production departments. Specially, the sales staff is not familiar to simulation studies. Therefore, a user-friendly interface is developed for the effective use of the simulation in the firm. The developed interface software has two modules: order analysis for sales department and scenario analysis for the production department. The screenshot of the interface software is given at Figure 1.

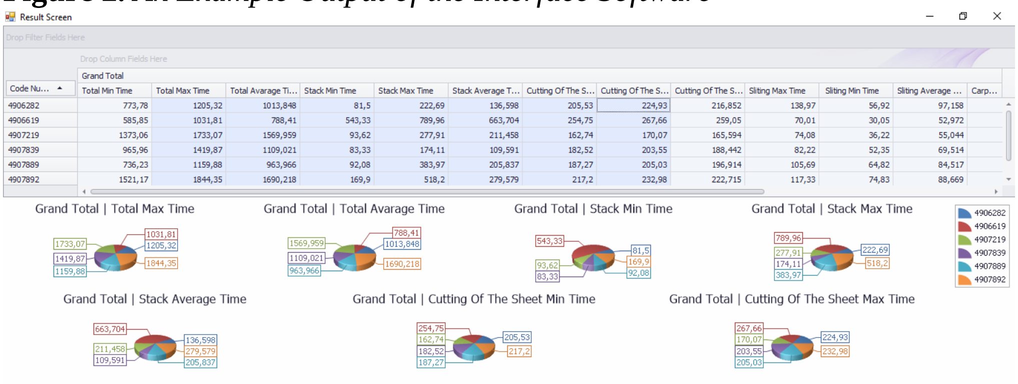
Figure 1. *The Screenshot of the Interface Software*



Sales staff enters technical specifications of current order to the simulation model by the aid of interface software. Thus, processing times, FT and DD can be estimated by the interface software embedded simulation model at a bidding stage. On the other hand, Scenario analysis module is used by the production department. The production department can make a scenario analysis for the processing time, FT and DD by changing the existing order in simulation.

The 95% confidence intervals for mean of operation times in carpenter, slicing, cutting and stacking operations, FT and DD for each group in the order are calculated by simulation as the outputs of interface software. Moreover, the best and the worst scenarios for FT and DD can be generated according to the result of replications in simulation and relative probabilities related to the completion time of each order group can be calculated by simulation as an output of the software. An example of the output that the interface software generates is given at Figure 2.

Figure 2. *An Example Output of the Interface Software*



An order list which includes 11 transformers in 6 groups is chosen for the verification of outputs. Technical specifications of group orders are completely different from each other and they cannot be given in this paper because of the firm's privacy policy. The actual processing times of selected groups of order are observed and given at Table 2. Simulation model runs according to the actual order in production and the calculated 95% confidence intervals for means of processing times are given at the same table in the terms of minutes.

Table 2. *Observed and Simulated Processing Times*

Product Code	Frequency	Observed Cabinetry Time	95% Confidence Interval For Cabinetry Time	Observed Cutting Slice Time	95% Confidence Interval For Cutting Slice Time	Observed Cutting Time	95% Confidence Interval For Cutting Time	Observed Stacking Time	95% Confidence Interval For Stacking Time
4907892	2	92	90.19 - 114.33	216	198.91 - 215.35	503	495.18 - 497. 61	1154	1152.3 - 1237.8
4907889	1	61	48.31 - 66.10	137	135.4 - 150.60	313	311.02 - 313.11	522	508.32 - 548.96
4907839	1	98	94.73 - 128.80	59	61.10 - 64.10	221	220.50 - 223.03	233	221.96 - 240.27
4906619	5	276	259.58 - 295.01	410	406.44 - 452.31	1153	1151.58 - 1156.94	1980	1960.5 - 2053.4
4906282	1	90	88.42 - 116.92	81	79.45 - 84.91	269	266.27 - 270.47	316	271.55 - 314.23
4907219	1	91	86.16 - 115.09	103	97.312 - 107.03	187	185.06 - 188.11	286	223.94 - 380.75

The observed FT and DD, and simulation results under 95 % confidence level are calculated and given at Table 3.

Table 3. *Observed and Simulated FT and DD*

Product Code	Frequency	Observed Flow Time	95% Confidence Interval For FlowTime	Observed Due Date	95% Confidence Interval For Due Date
4907892	2	2156	2015 - 2199	2908	2900.3 - 2952.9
4907889	1	1285	1121 - 1376	1901	1800.7 - 1915.2
4907839	1	720	685 - 796	1978	1911.0 - 1991.0
4906619	5	4250	4086 - 4580	5320	5102.8 - 5765.6
4906282	1	987	885 - 1112	1820	1733.9 - 1834.1
4907219	1	825	751 - 916	2408	2359.3 - 2591.8

According to the Table 2 and 3, it is clearly indicated that the predicted simulation results are between the bounds of the confidence interval. Therefore, it is clear that the simulation model generates successful outputs.

The developed simulation model and interface can be used as decision support software in the firm for both price offering at bidding stage and production scheduling.

Conclusions

This study focused on predicting the processing times, FT and DD of the customer orders those will be produced the first time in a transformer producer. For this purpose Arena simulation is used. Previously presented studies on this subject are used general job and shop characteristics and the processing times are thought to be known before starting the production. The novelty proposed by this study is using the technical specifications of the orders that are demanded by the customer directly. In this study, for the labor-intensive processes, probability distributions are used to predict the processing times while the processing times of machining processes are predicted by using regression equations. Also, interface software is developed. By using this interface the user enters the technical design parameters to the program and obtains the simulation results. The results indicate that using the technical specifications directly gives good results and accurate prediction can be performed.

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