Available online at http://ijdea.srbiau.ac.ir

Int. J. Data Envelopment Analysis (ISSN 2345-458X)

Vol.3, No.4, Year 2015 Article ID IJDEA-00345, 10 pages

Research Article

International Journal of Data Envelopment Analysis Science and Research Branch (IAU)

Utilizing Computer Simulation and DEAGP to Enhance Productivity in a Manufacturing System

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Received 13 January 2016, Revised 1 March 2016, Accepted 25 March 2016

Abstract

Generally, a typical problem which is crucial in a manufacturing system is increasing the production rate. To cope with the problem, different types of techniques are used in companies by trial and error which imposes high costs on them. Using simulation as a tool for assessing the effect of alterations on the performance of the overall system might be significant. This paper considers a simulation based data envelopment analysis goal programming (DEAGP) applied into a well-known automobile spare part manufacturer in Kurdistan to improve production rate. The objective is to develop a simulation model based on real system to identify the imbalances and improve the performance of production system. For this purpose, in 2013 data are collected from existing system and applying full factorial design of experiments technique, different scenarios have been considered then to find the best one we used data envelopment analysis goal programming technique as a method for measuring the relative efficiency of similar units. The results show that, the optimum scenarios are 5 and 8. Applying this method could conduct us to gain more than 1% improvement in production rate using the existing resources.

***Keywords**:* Computer Simulation; Production rate; Design of experiments; Data Envelopment Analysis Goal Programming

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Introduction

The Oxford English dictionary describes simulation as: “the technique of imitating the behavior of some situation or system (economic, mechanical, etc.) by means of an analogous model, situation, or apparatus, either to gain information more conveniently or to train personnel”. In simulation, a computer is used because of its speed in mimicking a system over a period of time. Again, most of these simulations could (in theory at least) be performed without a computer. But in most organizations, important problems have to be solved quickly. Computer simulation methods have developed since the early 1960s and may well be the most commonly used of all the analytical tools of management science [1].

In a study, Maria (1997) answered some critical questions regarding an overview of simulation modeling. The paper includes anyone who is involved in system design and modification such as; system analysts, management personnel, engineers, military planners, economists, banking analysts, and computer scientists. The study may useful for those unfamiliar with the area of discrete event simulation.

Simulation is a great tool for assessing systems, so simulation introduction is very useful. Introducing simulation and modeling and the main concepts in simulation is developed in Carson (2003)’s study. In addition, a number of key notes related to simulation team and managing a simulation project is presented through some guidelines in this study.

To predict the behavior of Polymer production process accurately and comprehensively, a study is done by Krallis et al. (2010). The goal of this study is to increase plant efficiency, improve product quality and decrease the impact to environment. Using a series of advanced software packages, a great number of polymerization systems are simulated. Thus, significant benefits are achieved on the polymer plant operability.

A review is done on commercial discrete event simulation software and its models by Cimino et al. (2010). In this survey some critical aspects such as domains of application, 3D and virtual reality potentialities, simulation languages and prices is considered. Moreover, a supply chain order performance simulator (SCOPS, developed in C++) is presented for investigating the inventory management problem along the supply chain under dissimilar supply chain scenarios.

A real time simulation model is developed for a modular housing production system in a study done by Ali et al. (2010). They mapped out the activities of a considered system and collected data of approximately 20 cycles for all activities at the assembly and subassembly stations. They observe the animation of the entities at a low speed run then, validate the model by comparing the production model performance measures with the real system outputs. The results show that the system is a bottleneck free system.

Regarding assembly lines in a production process which are supplied from a central logistic center and respecting the dependence of transportation requests on the warehouse picking process, the problem is considered as an integrated formulation problem in a study by Vonolfen et al. (2012). Using the transport simulation model they simulate the internal transport of parts between the warehouse and the individual workstations. They examined their approach in a scenario based on a real world data from Rosenbauer, one of the world's largest suppliers of firefighting vehicles. The results show that, warehouse optimizing leads to an efficient transportation in an integrated formulation problem.

Considering the incremental sheet forming (ISF), computer simulation is evaluated with real experiments by Lora et al. (2013). ISF is a process to produce the small batches of parts, rapid prototyping, and manufacturing flexibility with reduced operational cost. The results were consistent with the experimental manufacture of a symmetrical sample.

A review is done on simulation optimization algorithms and applications by Amaran et al. (2014). This document emphasizes the difficulties in simulation optimization as compared to algebraic model-based mathematical programming makes reference to state-of-the-art algorithms in the field, examines and contrasts the different approaches used, reviews some of the diverse applications that have been tackled by these methods, and speculates on future directions in the field.

The results of a simulation study concerned with the design of a service delivery system are presented in a study by Visintin et al. (2014). It shows how discrete event simulation can be used at the point of signing a long-term service contract to assess whether a service delivery system will be able to comply with the contractual terms over time and proposes a methodology based on the Monte Carlo simulation to estimate the service demand in a context where the installed base evolves dynamically over time. The research is based on real data from a leading global supplier of human to machine electronic controls operating in the aerospace industry.

A meta-analysis is developed by Oliveira et al. (2016) about the relationships and potential perspectives of modeling and simulation in supply chains. In order to establish a theoretical framework that improves the process of modeling, simulation and decision-making in supply chains, this systematic literature review exploring the state of the art in Supply Chain Simulation and analyzing the interfaces related to this field of research.

In this study, an ideas and solutions in deciding how to select an appropriate scenario to maximize production rate, which is the company's main goal, using a computer simulation model are introduced. Data envelopment analysis-goal programming, as a tool, is used to find the optimal scenarios.

This paper is presented as follows: in section 2 the system conceptual model presented and the seven performance measures used for fully system analysis. Section 3 shows computer simulation model of existing system applying the Enterprise Dynamics TM computer simulation package. In section 4 results and discussion are shown. Finally conclusions presented in section 5.

Conceptual model from real world

In this study, it is considered a case study of lifting gas manufacturing industries in Kurdistan which produces Pride's trunk jack with the physical characteristics of 16 millimeters pipe link to 8 millimeters shaft, how the behavior of a part of system during the time of analysis is captured in a critical path method (CPM) chart and depicted in "Fig.1" by Visio software.

Using 'circle' symbol as an activity symbol in the "Fig. 1", this chart is drawn and description of each system's activity, based on the figure, is indicated in Table 1.

For evaluating performance of the system (our case study), we define some performance measures (PFMs). These variables are defined as the outputs we want to collect. Table 2 shows PFMs of the manufacturing system.

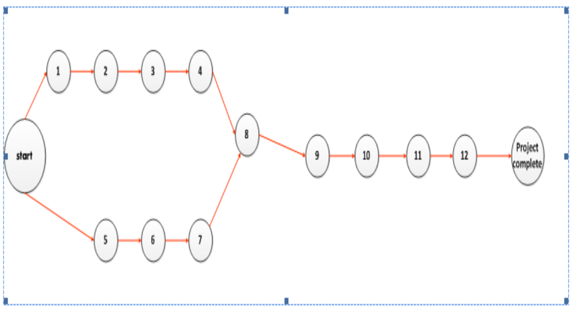

Figure 1. Critical path chart of manufacturing process in Gordon Pride's trunk jack factory

TABLE 1. ACTIVITIES IN GORDON PRIDE'S TRUNK JACK MANUFACTURING SYSTEM

Operations	Symbol
1	Cutting pipe
2	Drill
3	Argon welding
4	Press welding
5	Threaded shaft
6	Shaft polishing
7	Shaft assemble & rivet
8	Assembling shaft & pipe
9	Ring
10	Pneumatic press
11	Nitrogen charging
12	Washing

TABLE 2. PERFORMANCE MEASURES OF GORDON PRIDE'S TRUNK JACK MANUFACTURING SYSTEM (TIMES IN SECONDS)

PFMs	Description
Y_1	Average stay assemble
Y_2	Max output assemble
Y_3	Max output cutting pipe
Y_4	Average output queue number 10(Q10)
Y_5	Average stay Q15
Y_6	Average stay Q4
Y_7	Average output per a day(in 8 hours)

In the next section, simulation software used to model the manufacturing system. Using Enterprise Dynamics8 (ED) the conceptual model is converted. Regarding ED simulation software we use its special elements to describe the manufacturing process such as Assembler as an activity represents the assembling of shaft and pipe in this system.

Designing the simulation model

In this section, applying ED the converted model is depicted as follows.

In addition to the elements in ED reported, some special 4DScript coding is used to run the simulated current state model accurately. We have some extra operators in the factory, whom are used in some situations. So we defined a Team consists of 2 operators and allocated the operators to the required operations. Then, using 4dscript coding in the required atoms, we have these commands in the following Servers, namely shaft assemble and rivet (activity 7) and ring (activity9) (see table 1):

Server: Trigger on entry=
calloperators(AtomByName([Team],model),1)
Trigger on exit=
FreeOperators(AtomByName([Team],Model),i)

Another 4dscript coding is used for Assembler (assembling shaft and pipe), in this way:

Assembler: Trigger on entry=
calloperators(AtomByName([Team],model),1)
Trigger on exit=
FreeOperators(AtomByName([Team],Model),i)

Initial sampling information is based upon last six months. Then applying Minitab software and based on collected data, statistical distributions of activities and required atoms are determined and distribution parameters are recorded in the related atoms. The details are indicated in Table 3.

Then the requisite simulation adjustments for running the model in ED are made.

Simulation results

A.The current state simulation application of system

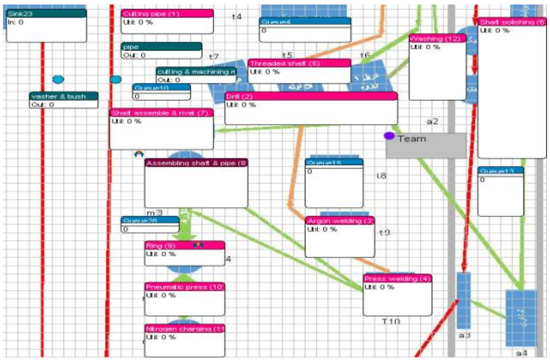

Figure 2. The snap shot of created simulating model using ED software

To express the performance of the proposed simulated model, applying ED software, these settings were done in Experimentation menu. In Experiment wizard the amounts of Observation, Number of observations and Warm up period are defined in the same sequence as 80 hours, 30 and 8 hours. Table 4 shows the PFMs of real system.

TABLE 3. STATISTICAL CHARACTERISTICS OF REQUIRED ATOMS IN GORDON PRIDE'S TRUNK JACK MANUFACTURING SYSTEM

Input var.	Var. code	Stat. dist.	Parameters
CT of Cutting pipe	CT1	Weibull	α = 1.36 β =0.8654
CT of Drill	CT2	Normal	μ=11.15 StDev=1.047
CT of Argon Welding	CT3	Normal	μ=12.64 StDev=1.379
CT of Press Welding	CT4	Gamma	α = 83.47 β =0.03027
Inter-arrival time of CMR		Normal	μ=19.5 StDev=0.9978
Time till first product of CMR		Normal	μ=19.5 StDev=0.9978
CT of Threaded Shaft	CT5	Normal	μ=5.322 StDev=0.5909
CT of Shaft Polishing	CT6	Normal	μ=3.046 StDev=0.4116
CT of Shaft assemble & rivet	CT7	Normal	μ=8.644 StDev=0.6
CT of Assembling shaft & pipe	CT8	Normal	μ=1.9 StDev=0.12
CT of Ring	CT9	Normal	μ=2.759 StDev=0.1596
CT of Pneumatic Press	CT10	Normal	μ=5.227 StDev=0.3667
CT of Nitrogen Charging	CT11	Normal	μ=20.06 StDev=0.6103
CT of Washing	CT12	Uniform	a=0 b=1500

α = Shape, β = Scale, μ= Mean, StDev=Standard Deviation, a=minimum value, b=maximum value

TABLE 4. THE PERFORMANCE MEASURES OF REAL SYSTEM (CURRENT STATE)

Y_1	7.65
Y_2	4274
Y_3	2879
Y_4	1477.07
Y_5	97486.49
Y_6	9546.27
Y_7	946

Afterwards, the results based on the real world situation are taken in to account as follows;

-The output of Cutting pipe is almost twice over the arrival of rebar to Threaded shaft. It is clear that, there may be some imbalances in doing activity 8, as it is an assembling operation requiring pipe and shaft (the output of activity 1 and the output of activity 7) to be complete. Therefore, the stay time of cutting pipe's output in the system will increase.

- There are 2 extra operators in the real system and they will assign to the activities 7, 8 or 9 whenever possible. Allocating the above number of operators in this way or even existence of them in the system is considerable and should be discussed.

All of the above arguments may affect the production rate of factory per a day and this is also an important problem.

B. The validity of simulation model

After the implementation of the current state ED model, it is crucial that the model represents the actual system performance.

Accordingly, it is important to validate the simulation model. Regarding this, the graphical difficulties of model has been resolved by experts in the manufacturing system and the final model was confirmed by the same key personnel and experts. Also, by performing a two sample nonparametric Mann-Whitney statistical hypothesis testing on the difference between the mean of the selected output of the computer simulation model (PFM) and the same data gathered from the real system, this kind of analysis is done. Based upon a 25 sample applied in the Minitab TM, p-value of 0.0786 for the Mann-Whitney statistics reject any evidence in mean differences at 10% significance level, consequently the ED model is ready to answer the question for which it was created to answer.

C. Scenario design

Design of experiment (DOE) method is used for designing scenarios and the methodology of full factorial DOE is applied.

DOE is a method to identify the important factors in a process then identify and fix the problem in a process. In real engineering settings, there are usually multiple factors involved and it is typically important to consider them together in case they interact.

Factorial design is a method to determine the effects of multiple variables on a response. This method reduces the number of experiments one has to perform by studying multiple factors simultaneously. Because factorial design can lead to a large number of trials, which can become expensive and time-consuming, factorial design is best used for a small number of variables with few states (1 to 3). Factorial design works well when interactions between variables are strong and important and where every variable contributes significantly.

We define input variable as X_1, X_2 and X_3 respectively as number of operators in a team, mean parameter of rebar's arrival rate and breakdowns of cutting pipe operation.

The following scenarios are defined based on DOE to increase productivity, efficiency and reduce waiting time in the system. Table 5 presents the coding of ranges in scenarios.

Then, based on Table 5 and full factorial DOE, the scenarios are created. Table 6 indicates the scenario design based on coded ranges

. D. Comparative table

Using data envelopment analysis goal programming (DEAGP) technique the proposed scenarios are compared. We have DEAGP model for 'n' decision making unit as follows.

TABLE 5. CODIFICATION PARAMETER SETTING

Input variables (X)	Low (-1)	High (+1)
X_1	0	5
X_2	9	19.5
X_3	0	Hr(6.5)

$$\min \sum_{j=1}^{n} \left(d_j^- + d_j^+\right)$$

$$st. \qquad (1)$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} + d_j^- - d_j^+ = 1 \qquad j = 1,2,\dots,n$$

$$u_r \geq \varepsilon \qquad r = 1,2,\dots,s$$

$$v_i \geq \varepsilon \qquad i = 1,2,\dots,m$$

$$d_j^- \geq 0 \qquad j = 1,2,\dots,n$$

$$d_j^+ \geq 0 \qquad j = 1,2,\dots,n$$

Where 'u_r', and 'v_i' are the weight to be applied to the outputs and inputs; and'd_i^+'and 'd_i^-'are deviations from the goals, the first one is over-achievement and the other one is under-achievement of the 'ith' goal. We considered each scenario as a DMU, since their inputs and outputs are the same. Then applying CCR model-a DEA model- on our data, the efficiency of each scenario is calculated Applying model (1), this one-stage efficiency computation leads to common set of weights amounts and by using the efficiency scores $\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}$, for each DMU, the relative efficiency of all DMUs will be evaluated. The most important advantage of the proposed model is calculating the efficiency amount of all DMUs with a single formula; it means that

TABLE 6. THE SCENARIO DESIGN BASED ON CODED RANGES

Scenario#	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7
1	+1	+1	+1	7.65	4277	2338	1476.6	94464.36	8879.03	958.5
2	-1	+1	+1	7.68	4320	2339	1476.97	104448.2	8801.13	949
3	+1	-1	+1	7.65	4276	2339	1685.07	103176.6	8914.13	927
4	+1	+1	-1	7.65	4276	2880	1477	93058.12	9546.6	932
5	-1	-1	+1	7.68	4320	2339	1908.27	174365.5	8964.2	961
6	-1	+1	-1	7.67	4320	2879	1476.93	95245.97	9532.5	950
7	+1	-1	-1	7.65	4275	2880	1683.9	110027.8	9549.13	938
8	-1	-1	-1	7.67	4320	2880	1904.03	174770.3	9529.33	957

all the DMUs are evaluated with common weights. So, they are compared on the same scale. Based on computations by Lingo the results are shown in Table 7.

It is clear that, higher efficiency indicates better scenarios. Therefore, scenarios with numbers '5'and '8' will be helpful in order to improve the situation of this system. We define DMUs with efficiency value equals to '1' as efficient DMUs (scenarios).

Conclusion

In this study, in order to improve the production of a manufacturing facility, a simulation model was created, taking into account numerous system constraints and process time logic based on statistical methods. This model was validated against

TABLE 7. THE PERFORMANCE MEASUREMENT OF SCENARIOS BASED ON DEAGP

Scenario #	Efficiency
Current state	0.456
1	0.457
2	0.461
3	0.990
4	0.457
5	1
6	0.461
7	0.989
8	1

CSWs: U1=0.1877646, U2=500919.7, U3=0.1000000E-04, U4=0.1000000E-04, U5=0.1000000E-04, U6=0.1000000E-04, U7=0.1000000E-04,V1=0.1000000E-04, V2=0.2404415E+09, V3=0.1000000E-04

d_1^+ =0.5433761, d_2^+ =0.5430556, d_3^+ = 0.5384615, d_4^+ =0.1018516E-01, d_5^+ =0.5431624, d_6^+ =0, d_7^+ =0.5384615, d_8^+ =0.1041666E-01, d_9^+ =0, d_i^- =0 for i=1,…..,9.

production rate and work centre utilizations within a 95% confidence interval.

Applying ED, the simulated model can allow various modeling scenarios to be examined in future simulations with less expense, time and resources than experimentation with the real world system. The results can then be analyzed and used to inform changes in manufacturing processes, system constraints and capital expenditure, in order to improve the production rate of the factory.

Using DEAGP method, the best scenarios are suggested with less calculation.

The study is applied in Gordon Pride's trunk jack factory and the result serves as a guideline for future production planning.

As it is taken from the results;

- Scenarios with numbers '5', '8', '3' and then 7 respectively are operational scenarios based on DEAGP model, in order to improve the situation of system using the existing resources.
- Applying scenario '5', the average output per a day is '961', which is the maximum production rate out of others.
- Maximum output of assembler (activity 8) is '4320', which belongs to the scenarios '5' and '8'.
- Maximum output of cutting pipe machine (activity 1) is taken by applying scenarios '7' and '8' with amount of '2880'.
- Scenarios with number '7' and '3' have the same amount of Average stay assemble (activity 8).

- Scenario ‘3’ has the minimum average stay for queue number 4 (working in process between activities 1 and 2) amongst efficient scenarios.

This study can be extended for future works in different ways,

- The scenarios will be more complete by extending the defined ranges in DOE.
- The proposed scenarios were focused basically on improving the production rate of the manufacturing system, while there are other important factors that could be considered such as minimizing waiting time (average stay) and so on.
- Cost analysis of each scenario by specifying cost functions is another future research which may be considered in addition to production rate to be as a multi-objective problem.

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