Prediction of Standard Times in Assembly Lines Using Least Squares in Multivariable Linear Models

Jhon Ramirez[1], Rodrigo Guaman[2], Eliezer Colina Morles[3], and Lorena Siguenza-Guzman[3](✉)

[1] Faculty of Chemical Sciences, Universidad de Cuenca, Cuenca, Ecuador
jhon.ramirez1707@ucuenca.ec

[2] Department of Applied Chemistry and Systems of Production, Faculty of Chemical Sciences, Universidad de Cuenca, Cuenca, Ecuador
rodrigo.guaman@ucuenca.edu.ec

[3] Department of Computer Sciences, Faculty of Engineering, Universidad de Cuenca, Cuenca, Ecuador
{eliezer.colina,lorena.siguenza}@ucuenca.edu.ec

Abstract. Currently, the highly competitive environment of the assembly industries has been an engine for them to seek differentiating factors for improving their efficiency. One of these factors is the study of times and methods (referred to the analysis and the critical and systematic examination of how a task is presently performed, facilitating to find more effective methods), which allows alleviating internal and external aspects that affect productivity and provides the basis for management decision-making. The present work has two primary objectives; firstly, the calculation of standard times within the enterprise operative area and, additionally, the development of a mathematical model for time prediction. For the fulfillment of these purposes, a referential conceptual framework was established about the study of time and the multiple linear regression model. This framework allowed elaborating a procedure for the development of the mathematical prediction model, together with its validation. The study concludes with a discussion on the importance of having models to estimate standard times in business decision making, and the establishment of relevant conclusions.

Keywords: Assembly · Linear regression · Process times · Work cells · Standard times

1 Introduction

Ecuadorian assembly companies face increasingly complex challenges generated by both external and internal factors. For instance, in the motorcycle assembly sector, there has been loss of market places as a result of government policies, which together with the dynamism of the Ecuadorian economy, the low purchasing power of citizens and the high unemployment rate, have generated a decrease in sales and therefore in motorcycle production [1]. Similarly, the automotive industry has been impacted by policies that

M. Botto-Tobar et al. (Eds.): ICAT 2019, CCIS 1195, pp. 1–12, 2020.
https://doi.org/10.1007/978-3-030-42531-9_36

affect its ability to compete fairly with imported vehicles, which enter the country with 0% tariffs [2]. In addition to the external factors mentioned, the assembly industries also present challenges caused by internal factors, such as limited resources and low productivity, which cause inefficient business performance, reflected in economic losses and market share. The most representative aspects of low productivity are the reprocesses, poor management of resources and methods, and downtimes [3]. Moreover, the decrease in productivity is greatly influenced by an excessive demand for operators' effort [4]. These factors can be summarized in terms of incorrect work-study.

Method engineering represents a systematic conception for the development of strategies that increase productivity in assembly industries, significantly optimizing their resources and providing tools to raise levels of competitiveness. Over the years, method engineering has developed improvement techniques focused on the study of work, in order to solve problems related to the inadequate administration of times and movements. The main objective of the study of work is to detect, reduce, or eliminate downtime by creating standards for the execution of tasks [5].

This work contemplates two intimately related fundamental aspects that, according to [6], are: the study of methods and the study of times. Through the former, the movements that an operator performs when executing a task are analyzed in order to find improvements to reduce or minimize the operating time [3, 7]. The measurements of the latter are taken as inputs to determine optimal times; that is, the time required for a trained worker to perform a specific activity [8]. In addition, with the establishment of standard times, it is possible to carry out other strategic processes such as production planning and cost calculation and productivity. Therefore, it is essential to focus on the study of times to raise the level of competitiveness. In turn, due to the changes that occur in the industrial assembly sector, it is necessary to develop tools that allow anticipating the internal behavior of the processes, with the aid of mathematical tools such as regression models.

2 Theoretical Background

The industrial and technological advancement led to the development of new tools to facilitate the work of the time analyst, allowing the conception of techniques for the determination of standard times [6]. This calculation can be obtained utilizing the following alternatives: estimates made by analysts, historical records, predetermined time systems, and chronometer time study [5]. The estimates made by analysts are based on the expertise of a person trained to determine the standard time most adjusted to the reality of the activity [9]. The determination of standard times T_E, by means of historical records, is based on time data of tasks performed in the past. For this, three values of time are taken into account: optimal time or optimistic time T_o, modal time or most probable time T_m, and most bulky time or pessimistic time T_a. For the calculation of the standard time, a weighted average of the mentioned values is used, according to the formula given by (1) [10].

$$T_E = \frac{T_o + 4T_m + T_a}{6} \tag{1}$$

One of the most advanced techniques for the study of times is the so-called Predetermined Time Systems, which is based on the use of databases with information on movements and their respective durations for the establishment of standard times [5]. Finally, the time study with a chronometer is the primary technique for measuring works. It is a direct method since the calculation of the standard time is based on the observation and timing of the various activities in a certain number of cycles [5]. The basic elements to carry out in this time study are a chronometer, time study form, and observation board [11]. The study of times with a chronometer can be divided into four steps, preparation, execution, evaluation and determination of supplements [12]. However, the International Labor Organization summarizes these steps in three: the selection of work to study, recording by direct observation of the process, and calculation of the standard time [11].

Standard times are indispensable inputs for correct decision-making [13], and therefore, they are significant factors to consider. With this argument, it is necessary to determine prediction models that allow obtaining standard times without the need to re-conduct field studies. A classical statistical technique to represent a process relies on linear regression models, which allow quantifying the link between one or more dependent variables based on values adopted by independent variables or regressors [14, 15].

To estimate the behavior of the dependent variable y, based on the values of the independent variables $x_1, x_2, x_3, \ldots, x_p$, it is necessary to construct a mathematical model as described in (2), based on a set of observations y_i, $i = 1, 2, \ldots n$, made on the production process. The estimated value of the dependent variable will be called y_e and can be represented by the linear, algebraic mathematical model, given by (3).

$$y = f\left(x_1, x_2, x_3, \ldots, x_p\right) \tag{2}$$

$$y_e = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_{\mathrm{p}} x_p \tag{3}$$

By defining the vector of coefficients $\vec{\beta} = \left(\beta_0 \beta_1, \beta_2, \ldots . \beta_p\right)^T$, and the inclusion of the independent variables in the vector $\vec{x} = \left(1, x_1, x_2, \ldots x_p\right)^T$, Eq. (3) can be rewritten in vector form, as showed in (4).

$$y_e = \vec{\beta}^T \vec{x} \tag{4}$$

The coefficients of the β vector are calculated using the least-squares method, by defining an objective function that reflects the quadratic differences between the measurements and the estimated value, as defined in Eq. (5).

Each observation y_i corresponds to a vector $\vec{x}_i$, and the concatenation of the vectors $\vec{x}_i$, *i = 1, 2, …, n* allows defining the matrix *(pxn)* of values $X = \left[\vec{x}_1 \vec{x}_2 \ldots . \vec{x}_n\right]$. In turn, the observation y_i *i = 1, 2, …, n* defines the vector of observations $\vec{y} = (y_1, y_2, \ldots, y_n)^T$. The coefficients β_i, $i = 0, 1, \ldots, p$ are calculated appropriately utilizing an optimization procedure. The solution to the problem of minimizing the objective function (5) is presented in (6).

$$J = \frac{1}{2} \sum\nolimits_{i=1}^{n} (y_i - y_{ei})^2 \tag{5}$$

$$\vec{\beta} = \left(X^T X\right)^{-1} (X^T \vec{y}) \tag{6}$$

The correlation between the dependent variable and the independent variables can be determined using the coefficient of determination R^2, defined by the equation in (7).

$$R^2 = \frac{SS_R}{SS_T} \tag{7}$$

In (7), SS_R represents the sum of squares of the regression given by (8), while SS_T is the sum of total squares given by (9).

$$SS_R = \beta^T X^T y - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n} \tag{8}$$

$$SS_T = y^T y - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n} \tag{9}$$

The value of the coefficient of determination belongs to the interval [0, 1], and its interpretation is as follows, the closer to 1 the value of R^2 is, the better the estimate given by (4); otherwise, the estimate will be inaccurate. Therefore, it is necessary to find R^2 values closest to 1 [16]. The linear correlation coefficient allows identifying the influence that an independent variable exerts on the dependent variable. This coefficient, defined through (10), is a good measure of the goodness of the regression line fit, and its values belong to the interval [−1, 1].

$$r^2 = \frac{S_{xy}^2}{S_x^2 S_y^2} \tag{10}$$

Where,

S_{xy}^2 = Covariance of xy
S_x^2 = Standard deviation of x
S_y^2 = Standard deviation of y

If the value of r^2 is equal to 1, then there will be an exact linear relationship between the independent variable and the dependent variable.

3 Materials and Methods

The present study contemplates the analysis of a motorcycle assembly plant; therefore, in the first instance, it is based on the processes carried out in [17]. Then, being the primary objective constructing linear mathematical models, which serve as instruments to predict standard times, variables related to the work environment, and the operator information of the motorcycle assembly plant were used. This plant produces seven different motorcycle models and consists of six assembly cells. In each cell, two operators work by performing simultaneous tasks both in the front and the rear of the motorcycle, in order to complete the product. The population consists of each motorcycle model and all operators within the assembly area, that is, 12 workers. The coding, M1, M2, M3, M4, M5, M6, and M7, was used for motorcycle models, respecting the confidentiality agreement established with the company.

3.1 Methodology

The research represents a case study of a longitudinal-non-experimental type since the analyst was in charge of handling the predetermined variables through *n* observations. It is also of a mixed nature due to the need for a documentary review of the various theories, strategies, and models about time standardization and multiple linear regression. The work required a field investigation for the collection of information directly from the source.

For the development of the time study, the methodology applied by the International Labour Organization (ILO) was used as a baseline. This is structured in three phases [11], selection of the job or position to study, registration of the process by direct observation, and calculation of standard time.

Phase 1. Selection of the Job or Position to Study. During the development of this phase, a detailed study was carried out on the process of assembling the products. Likewise, through direct observation, a diagram of the precedence of the activities of the process could be defined.

Phase 2: Registration of the Process by Direct Observation Using Appropriate Techniques. Once the job to be studied was selected, it was divided into several operations and these into activities with a clear beginning and end. To determine the operating cycle time, an initial sample was taken to define the number of cycles to be timed by using the Westinghouse table. This table provides the number of observations necessary depending on the duration of the process cycle [13, 18], which for this particular case resulted in three observations; however, five observations were made for a better interpretation of the actual data.

Once the number of observations was known, the time was recorded using three primary instruments: chronometer, observation board, and time study form [11]. For illustrative purposes, Table 1 shows a record of times observed on the rear part of motorcycles, in Cell 1.

Table 1. Times observed on the rear part, of Cell 1

	Observations					Average observed time T_{Op} (min)
	1 (min)	2 (min)	3 (min)	4 (min)	5 (min)	
M1	70.31	70.04	69.97	70.62	70.14	70.21
M2	78.39	77.47	75.62	77.89	78.56	77.59
M3	54.18	52.47	52.42	52.88	52.29	52.85
M4	49.00	49.19	49.19	49.60	47.14	48.82
M5	59.91	57.00	59.95	56.80	58.52	58.44
M6	57.48	57.53	57.73	56.65	57.72	57.42
M7	66.66	64.08	63.99	64.97	64.84	64.91

Finally, it was necessary to calculate the normal time T_N, which represents the qualification of the operator's work rhythm when performing a task. This is defined as the "time it takes for a qualified operator to perform a certain task or activity at a standard speed, without any delays due to personal or external situations" [19]. Normal time is calculated using (11).

$$T_N = T_{Op}\, x\, C \tag{11}$$

Where,

T_N = Normal time
T_{Op} = Average time observed
C = Performance qualification

The assignment of the work rate of the operators was carried out utilizing the Westinghouse method. The method, developed by Westinghouse Electric Corporation, takes into consideration four elements for assessing the pace of work: skill, effort, qualification, and consistency [9]. This method provided the data in Table 2 for the "Performance Qualification" of each operator. Table 3 presents an example of the calculation of normal time, based on the data in Table 1 relative to Cell 1.

Table 2. Westinghouse qualification system.

Operator	Ability	Effort	Conditions	Consistency	Qualification
Operator 1	0.03	0.02	0	0.03	1.08
Operator 2	0.06	0.08	0	0.03	1.17
Operator 3	0.03	0.02	0	0.01	1.06
Operator 4	0.06	0.02	0	0.01	1.09
Operator 5	0.06	0.06	0	0.03	1.15
Operator 6	0.03	0.02	0	0.01	1.06
Operator 7	0.03	0.06	0	0.01	1.1
Operator 8	0.06	0.06	0	0.03	1.15
Operator 9	0.06	0.06	0	0.01	1.13
Operator 10	0.03	0.06	0	0.01	1.1
Operator 11	0.03	0.02	0	0.01	1.06
Operator 12	0.06	0.02	0	0.03	1.11

Phase 3. Standard Time Calculation. With the knowledge of the normal time, the standard time T_E is calculated using the formula given by (12).

$$T_E = T_N(1 + S) \tag{12}$$

Where,
S = Supplements.

The value of the supplements is established by direct observation in the workplace, analyzing various aspects such as standing work, improper posture, use of force, light intensity, visual tension, mental tension, and mental tedium.

Table 3. The normal time of the rear - Cell 1.

	Average time observed (min)	Qualification	Normal time (min)
M1	70.21	1.17	82.15
M2	77.59	1.17	90.78
M3	52.85	1.17	61.83
M4	48.82	1.17	57.12
M5	58.44	1.17	68.37
M6	57.42	1.17	67.18
M7	64.91	1.17	75.94

For the development of the prediction model using the structure of multiple linear regression, it is necessary to select those variables that have more influence on the determination of the standard time. For this purpose, each value of the correlation coefficients was analyzed with respect to the standard time, defined by (10) [20]. As a result of this analysis, five independent variables $x_i, i = 1, 2, 3, 4, 5$, corresponding to age, weight, height, noise and illumination were selected.

Table 4 includes the correlation coefficient values of independent variables with respect to the standard time, based on the rear of the M7 model. Note that illumination and noise are the most correlated variables with the prediction of the standard time, followed by age and weight, while height affects less than 10% on the prediction. However, by introducing this variable in the linear model, an important adjustment in the prediction values was achieved.

Table 4. Selection of variables.

Variables	Coefficient of correlation $\boldsymbol{r}^2$
Age	0.137216543
Weight	0.123469244
High	0.081088858
Noise	0.261844676
Illumination	0.397216472

Tables 5 and 6 show the selected variables and their measured values, which are expressed in the following units: [age] ➔ years; [weight] ➔ kilograms; [height] ➔ centimeters; [noise] ➔ decibels; [lighting] ➔ luxes.

Thus, by matching the dependent variable y_e defined in (4) with the estimated standard time T_{Ee}, the mathematical model given by (13) is obtained, valid for both the front and the rear part of each motorcycle model.

$$T_{Eel} = \beta_0 + \sum_{i=1}^{5} \beta_i x_i \qquad l = 1, 2, \ldots, 7 \tag{13}$$

Table 5. Independent variables front-part from the motorcycle.

Variables	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Age	38	33	21	19	22	27
Weight	61	63	54	66	66	63
High	160	165	164	176	165	165
Noise	90	94	88	86	93	91
Illumination	194	187	214	178	189	194

Table 6. Independent variables back-part from the motorcycle.

Variables	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
Age	38	28	30	24	23	23
Weight	54	66	54	56	68	62
High	160	175	160	171	163	168
Noise	90	94	88	86	93	91
Illumination	194	187	214	178	189	194

By defining the vector $\vec{\beta} = (\beta_0, \beta_1, \ldots, \beta_5)^T$, and the vector $x = (1, x_1, \ldots, x_5)^T$, (13) can be represented in the vector form given by (14).

$$T_{Ee} = \vec{\beta}^T \vec{x} \tag{14}$$

The values of the model parameters are obtained by minimizing the objective function given by (15).

$$J_l = \frac{1}{2}(T_{El} - T_{Eel})^2 \quad l = 1, 2, \ldots, 7 \tag{15}$$

4 Results

Tables 7 and 8 include the standard times obtained from (12) for the motorcycle models considered.

Table 7. Standard time T_E for the front (min).

Model	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
M1	85.19	84.38	89.96	85.62	88.14	83.80
M2	89.18	89.88	86.80	89.74	91.35	87.15
M3	75.11	75.29	77.79	75.43	76.34	72.06
M4	62.07	58.93	64.14	60.87	58.79	58.49
M5	72.85	73.07	76.56	74.05	74.53	71.16
M6	66.47	63.23	69.27	67.53	68.00	63.68
M7	84.07	83.92	87.41	85.28	87.47	82.40

Table 8. Standard time T_E for the rear (min).

Model	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
M1	95.49	92.68	88.12	93.89	89.94	90.57
M2	107.12	105.65	99.17	107.47	100.31	102.62
M3	72.54	74.70	66.44	69.95	67.83	68.10
M4	67.41	66.91	62.59	65.72	63.42	64.86
M5	80.68	80.02	72.64	78.62	77.38	76.72
M6	79.27	77.66	73.18	78.54	75.00	75.30
M7	83.26	78.88	76.38	82.45	78.53	78.86

The minimization of the objective function was carried out by programming a spreadsheet, which allowed performing the matrix operations defined by (15). Tables 9 and 10 contains the linear models for the prediction of standard times for each motorcycle.

The use of (7) to calculate the coefficients of determination allowed to perform an analysis to corroborate the validity of the constructed regression models, resulting in 1 of both the front and rear part of each motorcycle model.

Table 9. Time prediction model for the front-part of the motorcycle.

Model	Equations
M1	$T_{Ee} = 815.92 - 1.16x_1 - 2.29x_2 - 1.87x_3 - 0.23x_4 - 1.17x_5$
M2	$T_{Ee} = 660.91 - 0.78x_1 - 1.65x_2 - 1.45x_3 - 0.03x_4 - 1.07x_5$
M3	$T_{Ee} = 921.05 - 1.17x_1 - 2.98x_2 - 1.98x_3 - 0.10x_4 - 1.51x_5$
M4	$T_{Ee} = 592.12 - 0.59x_1 - 1.85x_2 - 1.15x_3 - 0.58x_4 - 0.81x_5$
M5	$T_{Ee} = 721.91 - 0.96x_1 - 2.31x_2 - 1.51x_3 - 0.09x_4 - 1.14x_5$
M6	$T_{Ee} = 957.91 - 1.28x_1 - 2.46x_2 - 2.24x_3 - 0.77x_4 - 1.36x_5$
M7	$T_{Ee} = 885.64 - 1.23x_1 - 2.50x_2 - 2.01x_3 - 0.19x_4 - 1.36x_5$

Table 10. Time prediction model for the rear-part of the motorcycle.

Model	Equations
M1	$T_{Ee} = 88.19 - 0.23x_1 - 1.18x_2 - 0.10x_3 + 1.95x_4 - 0.41x_5$
M2	$T_{Ee} = 66.29 - 0.56x_1 - 1.99x_2 - 0.03x_3 + 3.25x_4 - 0.61x_5$
M3	$T_{Ee} = -16.77 + 0.07x_1 - 0.85x_2 + 0.17x_3 + 1.95x_4 - 0.37x_5$
M4	$T_{Ee} = 0.65 - 0.56x_1 - 1.68x_2 - 0.08x_3 + 3.05x_4 - 0.43x_5$
M5	$T_{Ee} = 54.04 - 0.23x_1 - 1.08x_2 - 0.12x_3 + 2.19x_4 - 0.43x_5$
M6	$T_{Ee} = 77.58 - 0.07x_1 - 0.75x_2 - 0.03x_3 + 1.24x_4 - 0.32x_5$
M7	$T_{Ee} = 120.62 - 0.23x_1 - 0.94x_2 - 0.20x_3 + 1.32x_4 - 0.34x_5$

5 Discussion

It is well known that the study of times represents an essential discipline for decision-making due to its contribution to the operational control of industries. This serves as a reflection of the situation they are living in and may raise awareness of improvement situations. In the present work, it was possible to determine various activities within the production process that do not add value such as transport and storage, the latter due to the nature of the production planning managed within the plant.

Referring to the standard time, it should be noted that it has a significant variation concerning the observed time, which ranges between values close to 30%. The present fluctuation is due to the manual nature of the work, which is executed in assembly cells made up of two operators. This value represents fatigue for them, among others considered for the determination of supplements, within the study of time with a chronometer.

It is worth mentioning that, according to the study [21], the chronometer time study has the participation of 89.5% concerning the other methods mentioned above. While it is true that there are more advanced techniques such as the Predetermined Time System, based on databases for the calculation of standard time, most time analysts, opt for taking time with a stopwatch. Although it represents a longer time, its main advantage is the reflection of the reality of the plant.

A recent study suggests the existence of a relationship between productivity, working conditions, and the environment, proposing a set of appropriate conditions for the good performance of a worker [22]. Likewise, it is known that ergonomics and productivity are interwoven in the prevention of ergonomic risks [23]. Thus, these arguments were considered in the selection of quantitative and qualitative variables for the construction of the time prediction model, which also constitutes a factor closely related to productivity. As a result of this approach, the variables illumination, noise, age, weight, and height served as the basis for the construction of linear prediction models suitable for estimating standard times associated with the assembly of seven motorcycle models. While it is true that regression models have been widely used in manufacturing processes, there is no background on its uses for predicting assembly line times.

Multiple linear regression analysis is essential to define the relationship between the dependent and independent variables in order to issue estimates and predictions within an adequate confidence interval. The present case shows a perfect relationship ($R^2 = 1$) between the selected independent variables (illumination, noise, age, weight, and height) and the dependent variable (standard time).

6 Conclusions

The standard time setting is a technique that, together with the work measurement, allows determining optimal times to operate processes, minimizing the amount of work, eliminating unnecessary movements, and replacing methods. Standard times thus facilitate the detection and reduction of downtime, to generate higher added value.

This article proposes a multiple linear prediction model structure for time prediction, whose main objective is to provide inputs for decision-making that allows for increased productivity. The study let to select important variables to model the behavior of the standard time and to validate the models constructed using the coefficient of determination, which concerning the accuracy of the adjustment. The model construction approach applies to other business scenarios with predictive purposes, such as sales forecast, staff turnover rate, among other possibilities.

The present study serves as the basis for future analysis on the prediction of times, in which it is possible to include other ergonomic variables, such as energy wear, mental load, and workload, to build better models.

Acknowledgments. This study is part of the research project "Modelo de Gestión para la Optimización de Procesos y Costos en la Industria de Ensamblaje," supported by the Research Department of the University of Cuenca (DIUC). The authors gratefully acknowledge the contributions and feedback provided by the IMAGINE Project team; similarly, to the management and operational staff of the motorcycle assembly, for their willingness to being analyzed as a case study.

References

1. Guevara, J.E.C., del Carmen Yacelga Rosero, C.: Análisis de los efectos de la aplicación de las salvaguardias en las importaciones y exportaciones en el intercambio comercial por carretera Ecuador-Colombia. SATHIRI 42–60 (2016)
2. Pico, L.M.P., Coello, R.R.C.: Análisis de la restricción a las importaciones del sector automotriz en el Ecuador periodo 2010–2015 y su impacto en la economía. INNOVA Res. J. **2**, 128–142 (2017)
3. Cardona Márquez, M.J.: Mejoramiento del tiempo de operación en procesos de ensamble bimanual basado en técnicas de optimización computacional (2016)
4. Moreno, L.A.M., Maestre, M.M., Flórez, L.A.F., Palomino, L.M.P., Villamizar, J.M.V.: Avances en el análisis del estrés laboral a partir de la captura de Neuroseñales en el cliente interno dentro de una organización textil en la ciudad de Pamplona. FACE Rev. Fac. Cienc. Económicas Empres. **17**, 81–90 (2017). https://doi.org/10.24054/01204211.v2.n2.2017.2648
5. Baca, G., et al.: Introducción a la Ingeniería Industrial. Grupo Editorial Patria, México (2014)
6. Rico, L., Maldonado, A., Escobedo, M.T., De la Riva, J.: Técnicas utilizadas para el estudio de tiempos: un análisis comparativo. Rev. CULCyT **11**, 9–18 (2005)
7. Rojas Ruiz, D.: Propuesta de estandarización de métodos y tiempos en el proceso productivo de la Empresa Industrias SUR EU (2016)
8. Maynard, H.B.: Maynard's Industrial Engineering Handbook. McGraw-Hill Education, New York (2001)
9. Freivalds, A., Niebel, B.: Niebel's Methods, Standards, & Work Design, 13th edn. McGraw-Hill Higher Education, New York (2013)
10. Caso Neira, A.: Técnicas de medición del trabajo. FC Editorial, Spain (2006)
11. Kanawaty, G.: Introduccion al Estudio Del Trabajo. OIT (1996)
12. Meyers, F.E.: Motion and Time Study: Improving Work Methods and Management. Prentice Hall, Upper Saddle River (1992)
13. Meyers, F.E., Stewart, J.R.: Motion and Time Study for Lean Manufacturing. Prentice Hall, Upper Saddle River (2002)
14. Castillo Morales, A.: Estadística aplicada. Editorial Trillas (2013)
15. Spiegel, M.R., Schiller, J.J., Alu Srinivasan, R.: Schaum's Outline of Probability and Statistics: 897 Solved Problems + 20 Videos, 4th edn. McGraw Hill Professional, New York (2013)
16. Freund, R.J., Wilson, W.J., Mohr, D.: Statistical Methods. Academic Press, Cambridge (2010)
17. Benavídez Vera, E.X., Segarra Farfán, E.M., Colina-Morles, E., Siguenza-Guzman, L., Arcentales-Carrion, R.: Levantamiento de procesos como base para la aplicación de sistemas de costeo basado en actividades en empresas de ensamblaje. Rev. Econ. Política. **30**, 40–71 (2019). https://doi.org/10.25097/rep.n30.2019.03
18. García, R.: Estudio del trabajo: ingeniería de métodos. McGraw-Hill, México (2000)
19. García, V., García, N., Patiño, V., Rondón, L.: Reubicación del almacén de equipos reparados y disminución de traslados de la empresa HIDROBOMBAS C.A para la mejora en su proceso aplicando las herramientas de Ingeniería de Métodos (2009)
20. Pértega Díaz, S., Pita Fernández, S.: Técnicas de regresión: Regresión Lineal Múltiple. Cad Aten Primaria. **7**, 173–176 (2000)
21. Ovalle, A.M., Cárdenas, D.M.: ¿Qué ha pasado con la aplicación del estudio de tiempos y movimientos en las últimas dos décadas?: Revisión de la literatura. Ing. Investig. Desarro. **I2D**(16), 12–31 (2016)
22. Nicolaci, M.: Condiciones y medio ambiente de trabajo (CyMAT). Hologramática. **8**, 3–48 (2008)
23. CROEM: Prevención de Riesgos Ergonómicos (2013)