International Journal of Research Studies in Science, Engineering and Technology
Volume 2, Issue 10, October 2015, PP 94-106
ISSN 2349-4751 (Print) & ISSN 2349-476X (Online)

Comparative Analysis between Welding Productivity in Laboratory and at Work Site

José Luiz Ferreira Martins[1]

[1]School of Engineering, Mechanic Engineer Department, Universidade Federal Fluminense, Post-Graduation Program in Civil Engineering, Post-Graduation Program in Industrial Construction, Niterói, Brazil.

Miguel Luiz Ribeiro Ferreira[2]

[2]School of Engineering, Mechanic Engineer Department, Universidade Federal Fluminense, Post-Graduation Program in Civil Engineering, Post-Graduation Program in Industrial Construction, Niterói, Brazil.

Cássia Andrea Ruotolo Morano[3]

[3]School of Engineering, Post-Graduation Program in Civil Engineering, Post-Graduation Program in Industrial Construction, Universidade Federal Fluminense, Niterói, Brazil.

Abstract: *This paper evaluates the feasibility of estimating welding productivity at the work site through productivity data obtained in the laboratory. Productivity behavior in the field and in laboratory was analyzed using Probability Density Function and Cumulative Probability Function curves that were developed through Monte Carlo Simulation based in field and laboratory samples. The field sample comprises 160 welded butt joints of carbon and low alloy steel and welding productivity data were collected by using the software Control Tub 5.3 in works performed at Brazilian refinery. The laboratory sample consists of 72 steel joints, welded by six qualified welders in 5 welding positions varying from flat to overhead. The unproductiveness was estimated by comparing productivity behavior in the field with laboratory. The analysis between welding productivity data of field and laboratory presented a strong correlation, so it was possible to deduce an equation that represents the unproductiveness in the field. The results showed that there is strong evidence that by knowing field unproductiveness and laboratory productivity of a welding procedure is possible to obtain an equation that explain the productivity at a specific field.*

Keywords: *Productivity, Unproductiveness, Monte Carlo Method, Welding.*

1. INTRODUCTION

This work is part of a series of studies related to the estimate of productivity in welding processes by simulation. The samples analyzed are made up of butt joints of carbon steel and low alloy, of carbon steels and low alloy ranked in accordance with the ASME Code Section IX (2004) as material p-number 1 welded to the shielded metal arc welding (SMAW) of industrial pipes performed in the field and carbon steel plates performed in several positions in laboratory environment. In Martins (2011) it was shown that the correlation between data productivity data of welded butt joints of industrial pipes and the modeling used in this laboratory job, where the specimens made are welded butt joints welded in different welding positions, simulating real welding conditions and varied diameter pipes is strong, which makes it possible to compare the productivity in both situations: field and laboratory. In this sense, the objective of this work is to verify the possibility of estimating the behavior of productivity in shielded melted arc welding in the field, knowing: the productivity in the laboratory under conditions of controlled work and the actual execution characteristics inherent to a construction site environment.

The correlation analysis between the two situations, field and laboratory, was held from modeled simulations based on real data, by the Monte Carlo Method. The purpose of verifying the existence of the correlation between the two situations resides in the fact that the productivity in the laboratory was measured with the process without any kind of interruption, which is called at work as an **intrinsic productivity**, whereas that of the field joints was obtained under normal production conditions, considering the production and unproductiveness times, which we agreed to call **global productivity.** Thus, if there is a correlation between the two conditions, one can conclude that it is possible to estimate the productivity in the field from that obtained in the laboratory. **Knowing the intrinsic productivity to the process, which is obtained without any interruption of the production process, and unproductiveness inherent to the work site evaluated.**

2. WELDING PRODUCTIVITY

In the methods and processes used in the construction industry, human, resources, materials and equipment are introduced, resulting in a product. Classically, productivity is defined as the ratio between the quantity of products and human resources used to obtain them. Thus, according to Diekmann and Heinz (2001), productivity is interpreted as the ratio of the amount of products obtained and the total number of Man-hours (Mh) consumed in the production process. In the case of welding, the concept of productivity used in the industry is, in general, the amount of weld metal deposited in relation to the amount of human resources consumed in welding expressed in [cm^3/Mh] or [kg/Mh].

In monitoring productivity in welding several indicators are mentioned in the literature, including those that consider only the deposition with the arc open and others that consider the total execution time of the joint, being that the latter are most commonly used in Brazilian industry, as seen in the Research Project Report "**Metrics of Industry Performance",** developed in the scope of the Oil and Natural Gas Industry Mobilization Program (PROMINP) (2010) prepared with the participation of the Brazilian construction industry, where standards for welding productivity indicators are established, among others. In the case of indicators that consider the total execution time of the joint, in their vast majority, they relate the weld metal volume, usually expressed in [cm^3], or mass deposited, usually expressed in kilograms [kg], considered in relation to the quantity of Man-hour (Mh) consumed in the welding operation. As to manpower, the following conditions are found: amount of MH only of welders; amount of Mh of the welders and helpers; and amount of Mh of the laborer, helpers and supervision of welding on the lowest level, which is normally entitled as in charge of welding by the Brazilian industry.

Other important works on productivity indexes in welding mentioned in the literature address the importance of this type of measure; among them, we highlight the considerations of Page and Nation (1967), which perform a comprehensive approach on the use of Man-hours in various scenarios and welding situations. The American Welding Society (AWS) (2002) provides eight types of general measure of productivity and Brito and Paranhos (2005) discuss the dependency of the welding process in the several methods used in the industry.

The indicators used in this article are based on field and laboratory data structured and used by Martins (2011) and Martins et al (2012) in which they report that the productivity of each welder‘s seal, in a certain number of days worked, which is expressed in [cm^3/Mh], as well as data extracted in the laboratory with the labor of each welder. Time measurements for evaluation of the equivalence of measurements were performed in the field, during the execution of the works with the permission of the companies and considering the actual situation of a construction site, in which the welder needs to stop for lack of material, to adjust the welding machine or some other activity or impediment related to the work environment and of the welder in the laboratory with controlled operational conditions and disregarding any type of interruption alien to the production process. In both cases, field and laboratory, the workforce considered in obtaining the indicators takes into account the welding activities performed by the welder. On the other hand, to measure the productivity it was considered that the beginning of time count should be the beginning of joint welding and the end after final cleaning, after the last pass.

It is also worth noting that in monitoring the overall productivity, one should take into account the lack of productivity in the construction site, which is inherent to the specific conditions of each workplace and those related primarily to human conditions. In this direction Adrian (2004) mentions that in the U.S. construction industry the lack of productivity reaches on average 50% for a working day of eight hours; that is, four hours of actual work performed. With respect to human needs, still based on studies of the U. S. construction industry, the author reports that 15 to 20% of this working day is consumed with the purpose, namely, in 8 hours, 6.4 to 6.8 hours are actually dedicated to the production activity, which one might represent as the maximum possible performance condition to be achieved under normal conditions.

3. MONTE CARLO METHOD

The Monte Carlo Method has as principle the generation of pseudo-random numbers as of samples of data taken from the object of interest. In Morano and Ferreira (2003) the procedure of using this method is summarized in the following sentences: 1 - Collate data collected on a table with class intervals, from which a frequency histogram will be constructed; 2 - Choose from a distribution whose probability density function (PDF) is a continuous random variable that best represents the sample data organized in accordance with step 1; 3 - After the implementation of steps 1 and 2, execute the simulation based on the distribution defined in 2, considering the class intervals established in 1; 4 - Evaluate if the amount of random numbers in the simulation performed is satisfactory, being that otherwise, step 3 should be repeated until the number considered as ideal is reached; 5 - Based on the amount of pseudo-random numbers generated in 4, obtain the accumulated probability function (APF) from which the analyses will be made.

According to Zio et al (2006), Tipper (2008) and Wu (2008), the generatrix for simulation is defined using the Beta curve. On the other hand, Gupta et al (2008), Royall (1997), Triola (1999), Nascimento et al (2003) and Batista et al (2002), consider the maximum likelihood method for evaluation of the function that best fits each sample. According to Rodrigues (2001), Morano (2003) and Constâncio (2009), the generatrix for simulation is defined by using the Beta curve or by selecting the best-fit curve for the samples data obtained in the chi-square test. In this work, the choice of the generatrix was performed by the resources of the @Risk (2013) through the best classification obtained in the chi-square test, among the possible curves selected by the software as of the samples under consideration.

In this article, the number of classes and the criteria to define the amount of pseudo-random numbers to be generated for the simulation were established in accordance with the recommendations provided in Cochran (1982), Rodrigues (2001), Morano (2003) and Martins (2011), which are: 1 - Defining the number of classes by Sturges Rule; 2 - Amount of the pseudo-random numbers chosen in the Palisade Corporation @Risk software release 6 (2013) with 10000 numbers; 3 - Evaluation of the amount of the pseudo-random numbers by class; 4 - Adherence test of the set of pseudo-random numbers generated by simulation with the generatrix used; 5 - Validation of the simulation made. The computing environment used for evaluation functions that best adhere to the samples and the simulations was that of @Risk (2013).

4. EXPERIMENTAL PROCEDURE

The experimental procedure consists of the acquisition, processing and simulation of field and laboratory data with a view to evaluating the productivity and non-productivity of the process under analysis.

4.1. Base of Field and Laboratory Data

The experiment was conducted from a database obtained from welded field joints and another in laboratory under controlled conditions. Two situations were analyzed: 1 - Existence of correlation between real databases; 2 - Existence of correlation between samples obtained by simulation from the actual database.

The data of the joints produced in the field were owned and recorded in the work developed by Gioia and Siva Junior (2007) and revised by Martins (2011) for welding of butt joints in industrial steel pipes, classified as materials p-number 1 according to code ASME Section IX (2004), collected in works performed at REDUC (Duque de Caxias Refinery, Rio de Janeiro, Brazil), where software ControlTub 5.3 was used to record the acquisition. This program transforms the several diameters into equivalent joint (JUEQUI), which subsequently are treated and owned in [cm^3/Mh]. A JUEQUI is agreed to as a joint with a diameter of 4" Schedule 40 (OD = 114.3 mm, ID = 102.26 mm, wall thickness = 6.2 mm); for other correspondences with this convention are established. Every joint is associated with a welder's seal and productivity is calculated cm^3/Mh.

Productivity measures are based on the operating conditions of deposition of welding consumable by the welder in each hour of work. These data were collected from service companies in the area of the oil refinery, where it was considered the minimum ownership of 10 days actually worked and expressed in [cm^3/Mh].

The laboratory data are based on Martins's work (2011) and obtained under controlled conditions in a laboratory environment. In laboratory data the productivity measure of six welders was made in twelve specimens each making up a total of 72 specimens. Both the welders who performed joints welded in the field and in the laboratory are qualified in accordance with ASME code Section IX (2004). The welding positions of each specimen corresponding to each welder were selected at random, by drawing lots, among the positions presented in Figure 1. These data were introduced in a spreadsheet, processed and presented with dimensional [cm^3/Mh], in an analogous way to those collected in the field. The positions of the specimens that were welded in the laboratory abide by the positions shown in Figure 1 and the amounts drawn at each position are shown in Table 1. These positions were used to enable correlation with field productivity data, simulating varied diameter pipes in a similar way to software Controltub using JUEQUI. The laboratory specimens consist of flat plates welded to the top of the weld bead of 150 mm in length. To facilitate notation and considering the condition suggestive of an amount of elements in each sample, the field sample was named 160el and the laboratory sample was named 72elLab.

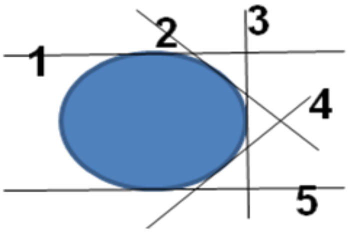

Figure1. *Welding positions in laboratory*

Table1. *Number of specimens in each welding position in the Laboratory*

Position	**Quantity (un)**	**Percent (%)**
1 (0^{o})	**16**	**22.22**
2 (45º)	**14**	**19.44**
3 (90º)	**17**	**23,62**
4 (135º)	**14**	**19.44**
5(180º)	**11**	**15.28**
Total	**72**	**100,00**

Field sample data 160el present values of productivity in overall condition considering the welded joint fully implemented. For the data of the laboratory sample 72elLab the sum of all intermediate times were considered, from the filling going through the filling cleaning, in continuity with the deposition of the finish and ending with the final cleaning and closing of the joint. Table 2 presents the statistical data of the samples 72elLab and 160el respectively.

Table2. *Statistics of Laboratory and Field Reference Samples [cm^{3}/Mh]*

Statistics	**72elLab**	**160el**
Max	92.6	130.3
Mín	35.3	2.4
Avarage	60.9	26.1
S Deviation	11.6	18.8
Coef Variation	0.19	0.72
Mediane	61.2	20.7

4.2. Correlation between Productivity in the Laboratory versus Productivity in the Field

The experiment performed consists of comparing the behavior of the database made up of the 160 field sample elements, 160el, and the database built in the laboratory with 72 elements, 72elLab, with the respective simulations using the Monte Carlo Method. The phases of their performance have the following structure: 1 - Definition of the generatrix and the histogram classes for simulation from each sample considering the criteria of adherence test established by @Risk (2013) with a significance level of 99%; 2 - Simulation with the generatrix chosen in the previous step; 3 - Comparison of the PDF and APF of the reference samples evaluated with the simulations performed; 4 - Organization of the reference sample data and the sample simulations to enable the evaluation of laboratory and field data correlation.

In defining classes for preparation of histograms, using the criterion of Sturges and establishing the amount of pseudo-random numbers, one considers the recommendations of Cochran (1982), Rodrigues (2001) and Morano (2003). Therefore, the classes defined are considered from six up to the value established by the software used to view PDF and APF of each sample and from then one, the simulation process can be started. The whole computational structure used in the calculation of functions, statistics and graphs generated follow the guidelines of the @Risk (2013) program, which are aligned with the observations of the authors mentioned. Thus, with the sample, the PDF, the significance level established the number of classes to be used and the definition of the amount of pseudo-random numbers, the Monte Carlo simulation is run. The pseudo-random numbers generated are distributed into classes established in the distribution of the samples and thus the PDF and the FPA are identified for each simulation as well as their adherence tests. In parallel, we calculate the statistics of each simulation. Having the data from the simulations of samples and sorting them in ascending order, the correlation of productivity values is established, obtained in the laboratory with the field values. In parallel, it is generated based on the simulations, the curve that shows the behavior of non-productivity at the work site studied, which was defined as the percentage of non-productive hours of the welders at the work site, according to Equation (1).

$$I = (1 - PI/PG) X100 \tag{1}$$

where,

I = Non-productivity (%);

PG - Global Productivity (cm3/Mh) and

PI - Intrinsic Productivity (cm3/Mh).

5. RESULTS AND DISCUSSION

In the analysis of the results we compared the behavior of PDF and APF, both of field samples and laboratory samples, as to the curves generated by simulation. Based on the analysis performed by Martins (2011) below we present the PDF and APF resulting from the evaluation of the reference samples, as well as their respective simulations and correlation analysis in which it was used simulations of welded plates used in various positions in the laboratory, revealing good adherence with the data obtained by the ControlTub program in the field, as observed in the correlation curve between the sample simulations.

5.1. APF of Field, Laboratory Samples and Respective Simulations

Samples 160el and 72elLab represent real productivity data in the field and in the laboratory. The simulation of each corresponding sample should exhibit similar behavior so that it can be considered representative of the actual production process. By observing the results presented, it can be stated, with a significance level of 99%, that the simulations of the samples present a shape similar to the curves of the reference samples, using the functions defined by the criteria of @Risk (2013).

In Figure 2 it is shown the representations of the PDF and the APF of the field sample 160el. The discrete PDF of the sample resulted in the continuous PDF that best fits that of the sample with the RiskPearson5 (3.9665, 90.498) function according to the @Risk (2013). It is observed that in the resulting APF the probability of occurrence of the productivity values greater than 5% and less than 90%, is located between values of 7.5 and 62.0 cm^3/Mh and the average is 26.1 cm^3/Mh.

Figure 3 shows the representations of the PDF and the APF of the reference laboratory sample 72elLab. The discrete PDF of the sample resulted in the continuous PDF that best fits that of the sample with the RiskLogistic (60,6607;6,4212) function of @Risk (2013). It is observed that in the resulting APF the probability of occurrence of the productivity values greater than 5% and less than 90%, is located between values of 40.9 and 78.8 cm3/Mh and the average is 60.9 cm3/Mh.

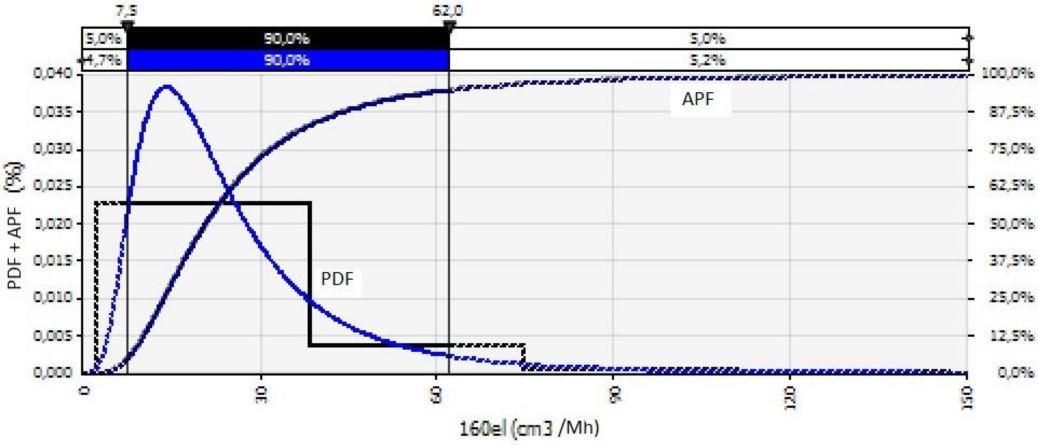

Figure2. *PDF and APF Adjusted by continuous functions of Field Sample 160el*

The simulations of the samples were performed in @Risk (2013), with the generation of an amount of 10,000 pseudo-random numbers whose statistic is presented in Table 3. These simulations were validated in accordance with the statistical criteria established by the program.

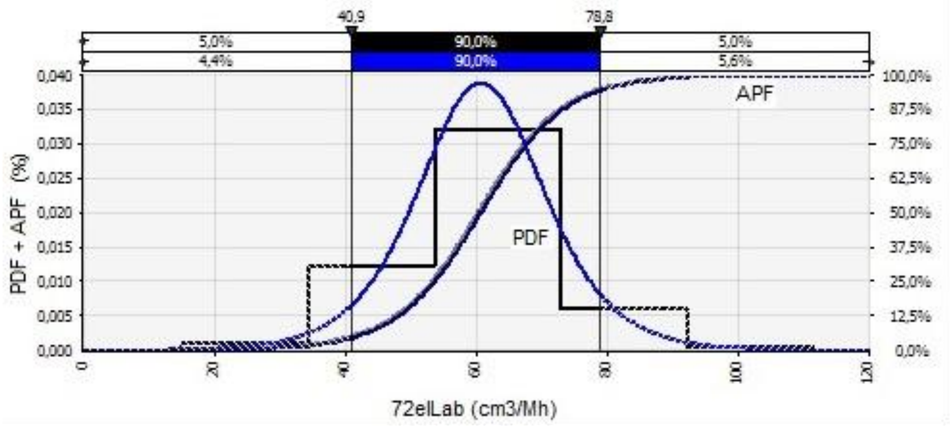

Figure3. *PDF and APF Adjusted by continuous functions of Laboratory Sample 72elLab*

Table3. *Statistics of Laboratory and Field Sample Simulations [cm^3/Mh]*

Statistics	**72elLab Sim**	**160el Sim**
Max	114.5	355.2
Mín	0.00	2.3
Avarage	60.5	26.4
S Deviation	11.7	21.2
Coef Variation	0.19	0.80
Mediane	60.6	20.8

Figure 4 shows the distributions related to information about the simulation of sample 160el. Thus, it is shown the PDF and APF resulting from the classification of the random numbers generated by the computing environment. It is observed that in the resulting APF the probability of occurrence of the productivity values greater than 5% and less than 90%, is located between values of 7.5 and 62.0 cm3/MH and the average is 26.1 cm3/MH.

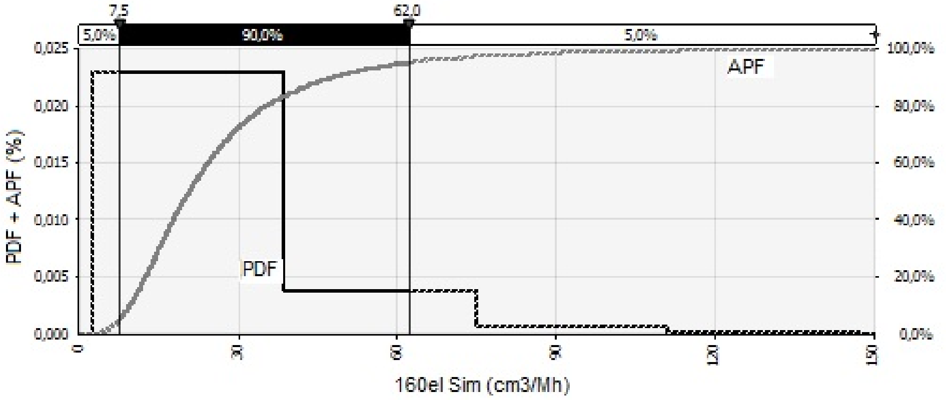

Figure4. PDF of APF and Simulation by MMC of the Field Sample 160el

Figure 5 shows the distributions related to information about the simulation of sample 72elLab. Thus, it is shown the PDF and APF resulting from the classification of the random numbers generated by the computing environment. It is observed that in the resulting APF, the probability of occurrence of the productivity values greater than 5% and less than 90% is located between values of 40.9 and 78.8 cm3/Mh and the average is 60.2 cm3/Mh.

Observing the behavior of the simulations and the corresponding statistical values one can state that the simulations adequately depict the behavior of the corresponding samples.

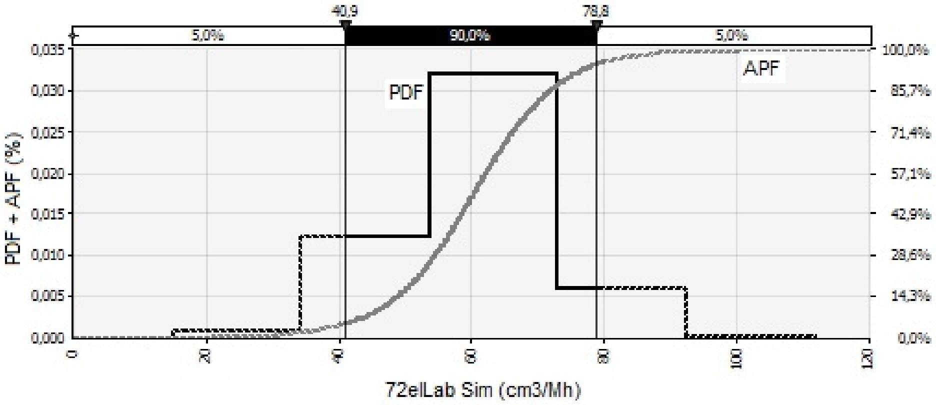

Figure5. *PDF of APF of the Simulation by MMC of the Laboratory Sample 72elLab*

5.2. Correlation Analysis of Productivity in the Field with of the Laboratory

Different operating conditions of construction sites influence the overall productivity of production processes, since they interfere with the continuity of the same. Thus, the overall productivity of a particular construction site is directly influenced by events that disrupt or prevent the continuity of the process. The sum of all these occurrences is called lack of productivity and can be represented with the corresponding PDF and APF. Thus, to analyze the behavior of the overall productivity at the jobsite, two important parameters must be taken into consideration:

1 - Operating conditions of the construction site, such as: location, distance, displacement, access, scaffolding, waiting time, preparation time of the joint, supply of equipment, availability of consumables, weather, restrictions and all aspects related to the work environment installed to perform the task.

2 - Intrinsic productivity of the welding process represented by the welding procedure, the ability of the welder, the volume variations permitted by the applicable standard and all other aspects related to the task itself.

This article aims at showing that it is possible to correlate the intrinsic productivity of the process, under controlled laboratory conditions and without any interruption with actual execution conditions under jobsite conditions. If there is this correlation, we can estimate the behavior of overall productivity in a given work site from the intrinsic productivity, knowing the behavior of lack of productivity in each place under consideration.

Regression is used to establish a ratio among variables, here specifically between the simulation of samples in accordance with Triola’s guidelines (1999). Considering the use of linear or polynomial regression, Equation (2) is established, which is used for both conditions. The linear and polynomial regressions were performed in Matlab (2007, 2001) environment, in which the values of the vectors were classified in ascending order represented by 10,000 pseudo-random numbers generated in the @Risk (2013) environment of each vector of 160el and 72elLab simulation. The variable "x” represents the productivity observed in the laboratory and corresponds to intrinsic productivity represented by the simulation of sample 72elLab. The variable "y” represents the overall productivity observed in the field and represented by the simulation of sample 160el.

$$y = a_n \cdot x^n + ... + a_1 \cdot x + a_0 + \varepsilon \qquad (2)$$

Considering the linear condition, it is observed in Table 4 the coefficients of the straight line that correlates the data considered. Figure 6a shows the straight line, which presents a correlation coefficient of 0.8572, which corresponds to a strong correlation between the simulations of the samples. Table 4 also shows the corresponding coefficients, the polynomial regression of third degree. Figure 6b shows the adequacy of the polynomial to the values of the simulations of the samples considered.

Table4. *Regression Coefficients of Field and Laboratory Sample Simulations*

Sample simulation / Coefficients	a_3	a_2	a_1	a_0
72elLab X 160el linear regression	0	0	1,568777	- 68,327002
72elLab X 160el polynomial regression	0,0006271	- 0,0682218	2,6534545	- 29,240939

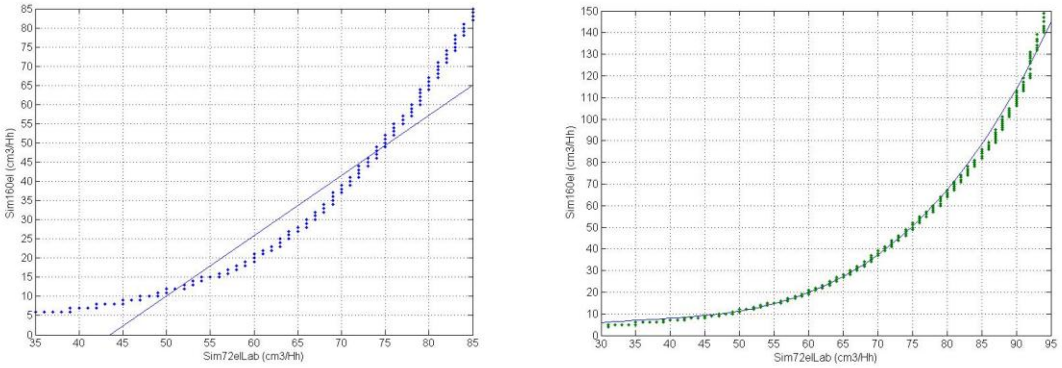

Figure6. *Regression between the Simulations of Samples 72elLab and 160el*

5.3. Behavior of Unproductiveness at the Work Site

Figure 7 shows the APF of the unproductiveness, which was adjusted by @Risk (2013) through the RiskExtValueMin (71.844; 156.6575) function, as defined previously, which represents the probability of occurrence of idle percentage of the workforce at the work site analyzed, that is, at the Duque de Caxias Refinery (Rio de Janeiro, Brazil). In this case, the factors that govern this curve are related to actual implementation conditions at the construction site. On the other hand, it was demonstrated that there is a strong correlation between the overall productivity at the construction site and the intrinsic productivity in the laboratory. Thus, if the curve of unproductiveness developed represents the workforce idleness at the construction site and knowing the intrinsic productivity relative to the welding procedure in question it is possible to estimate with a reasonable degree of accuracy the behavior of the overall productivity at the construction site. Considering that the curve of unproductiveness developed in this work is a function of variables inherent in the conditions of the construction site of the field sample studied, which are independent of the performance obtained in the laboratory, it can be concluded that it is feasible to estimate the productivity in the field, although it would be necessary to know the intrinsic productivity in each case.

For the case analyzed in this work, observing Figure 7, it appears that the probability of occurrence of unproductiveness below 20% tends to zero. This trend is consistent with the assertions of Adrian (2004), based on data from the U.S. construction industry, where the author states that for a journey of 8 hours of work a normal human being consumes from 15 to 20% of his time for needs inherent to human conditions. Likewise, however, according to the same author, idleness observed at the construction site in the United States lies in the range of 50% of the working day; in the case of the curve obtained, the average obtained was of approximately 63%, being that in PROMINP's report (2010), addressing reports of work relative to the verification of unproductiveness in Brazil, the values are very close to those presented. Considering the average unproductiveness (63%), as shown in Figure 7, corresponding to a 37% occupancy factor, the average intrinsic productivity is of 60.5 cm^3/MH as shown in Figure 5 and Table 3, and the estimated overall average productivity is obtained by the multiplication of 60.5 X 0.37 = 22.385cm^3/MH. Observing Figure 4 and Table 3, the average obtained for the overall productivity is 26.4cm^3/MH. Thus, it appears that the probability of occurrence of values above 60.5cm^3/MH, which corresponds to the average of the intrinsic productivity, it tends to zero, which would be expected, since it is related with conditions envisaged of the production process.

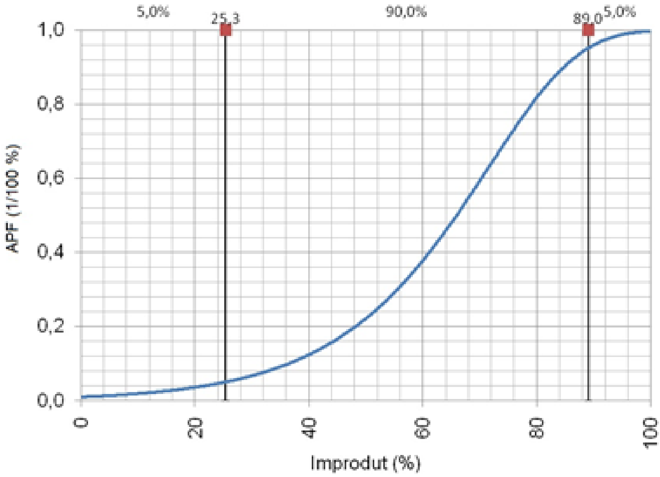

Figure7. *Unproductiveness at the Work Site*

The analysis of these data leads to the conclusion that there is evidence of the possibility of estimating overall productivity occurrence probability for other welding procedures, involving even other processes, knowing the behavior of the taskforce idleness at construction and the intrinsic productivity of the evaluated process. However, for a definitive conclusion on this statement analyses must be performed similar to the one presented in this work for other welding procedures.

6. CONCLUSIONS

The analysis of the results demonstrated the suitability of the model used in the laboratory to represent the conditions of field execution, considering different welding positions and varying diameters. Thus, it was possible to evaluate the existence of correlation between productivity data at the construction site with those obtained in laboratory.

The strong correlation presented between the productivity data in both situations under study shows that it is possible to estimate the productivity at the construction site from performance data obtained in the laboratory.

By confronting the unproductiveness curve of the construction site obtained in this work together with the productivity data obtained from the field and laboratory, it appears that it is possible to estimate productivity at the construction site, knowing the unproductiveness curve at the work site and the productivity of the welding procedure studied in the laboratory. To consolidate this conclusion for different welding processes of the shielded metal arc welding, an analysis of samples from other procedures is required.

The simulations obtained by @risk proved to be of great value to the establishment of regression and correlation of samples with different amounts of constituents, presenting good adherence between the PDF and the APF presented by the samples considered and those obtained in the simulations.

REFERENCES

[1] ADAM, James J. Construction Productivity Measurement and Improvement. Stipes Publishing. USA. 2004. p 558.

[2] AWS - American Welding Society. Welding – Related Expenditures and Productivity Measurement in U.S. Manufacturing, Construction, and Mining Industries. 2002. 90 p.

[3] BATISTA, J. L. F. ; COUTO, H. T. Z. . A razão de verossimilhança como alternativa aos testes de aderência: um exemplo de distribuição diamétricas de florestas tropicais. . In: 47a. Reunião Anual da Região Brasileira da Sociedade Internacional de Biometria (RBRAS) - Programa e Resumos, Rio Claro, 2002. p. 42-48.

[4] BRITO, J.D.; PARANHOS, R. Como Determinar os Custos da Soldagem, 2005.

[5] COCHRAN, W. G. (1954), “The combination of estimates from different experiments”. Biometrics, 10, 101-129. Also Paper 58 in Cochran (1982).

[6] CONSTÂNCIO, D. S.; FERREIRA, M. L .R.; FREIRE I. J.. Estimativa de Produtividade na Soldagem de Tubulações Industriais utilizando o Método de Monte Carlo. XXXV CONSOLDA – Congresso Nacional de Soldagem; ABS – Associação Brasileira de Soldagem. Piracicaba, São Paulo, Brasil. 2009.

[7] DIEKMANN, J.E.; HEINZ, J. Determinants of Jobsite Productivity. CII, 2001. 144 p.

[8] GIOIA, A. L. S.; JUNIOR, I. F. da S. Avaliação de Metodologia para Medição da Produtividade na Atividade de Montagem de Tubulação em Obras Industriais. Niterói, 2007. 52 f. Monografia (Pós-Graduação em Montagem Industrial e Fabricação Mecânica) – Escola de Engenharia, Universidade Federal Fluminense, Niterói, 2007.

[9] GUPTA, A.; MUKHERJEE, B.; UPADHYAY, S.K. Weibull extension model: A Bayes study using Markov chain Monte Carlo simulation, Department of Statistics, & DST Centre for Interdisciplinary Mathematical Sciences, Banaras Hindu University, India, Reliability Engineering and System Safety 93 (2008), pp 1434–1443. 2008

[10] MARTINS, J. L. F. Aplicação de Simulação com os Métodos de Monte Carlo e Hipercubo Latino na Estimativa da Produtividade no Processo de Soldagem por Eletrodo Revestido. Niterói. 2011. 293 f. Tese (Doutorado – Tecnologia da Construção) – Programa de Pós-Graduação em Engenharia Civil – Universidade Federal Fluminense, Niterói, Rio de Janeiro, Brasil. 2011.

[11] MARTINS J. L. F., Ferreira, M. L. R. e Saraiva, J. M. F., 2011, “Estimativa da Produtividade em Soldagem pelo Método de Monte Carlo”, Soldagem & Inspeção, 16, 03, PP.204-212.

[12] MARTINS, J. L. F.; Ferreira, M. L. R.; Pardal, J. M. e Morano, C. A. R., 2012, “Comparación de la estimación de la productividad del proceso de soldadura eléctrica por los métodos de simulación de Monte Carlo e Hipercubo Latino”. Información Tecnológica. 23(4).

[13] MATHWORKS. MATLAB – The language of technical computing. Using MATLAB. Ver.6. The MathWorks, Inc. Natick, MA, USA. 2001.

[14] MATHWORKS. Statistics Toolbox™ 6. User’s Guide. The MathWorks, Inc. 2007.

[15] MORANO, C.A.R.; FERREIRA, M.L.R. Aplicação do Método de Monte Carlo em Análise de Riscos em Projetos de Construção. Niterói, 2003. 7 p.

[16] MORANO, C.A.R. Aplicação das Técnicas de Análise de Risco em Projetos de Construção. Niterói, 2003. 205 p. Dissertação (Mestrado em Engenharia Civil) – Programa de Pós-Graduação em Engenharia Civil, Universidade Federal Fluminense, Niterói. 2003.

[17] NASCIMENTO, L.S.V., CAMPOS, J.N.B. e STUDART, T.M.C. ANÁLISE DA EFICIÊNCIA DOS MÉTODOS DOS MOMENTOS E DA MÁXIMA VEROSSIMILHANÇA NA ESTIMATIVA DE PARÂMETROS DA DISTRIBUIÇÃO GAMA II: UMA ABORDAGEM PROBABILÍSTICA In: XV Simpósio Brasileiro de Recursos Hídricos, 2003, Curitiba. XV Simpósio Brasileiro de Recursos Hídricos. Porto Alegre: ABRH, 2003.

[18] PAGE, J.S.; NATION, J.G. Estimator’s Piping Man Hour Manual, First Revision, Gulf Pub Comp. Houston. Texas. 1967. 157p.

[19] PALISADE CORPORATION. @RISK – Add-In do Microsoft Excel para Simulação e Análise de Riscos. Manual do Usuário. Versão 6. Palisade Corporation: Ithaca, Ny USA, Março, 2013, 941 p.

[20] PROMINP (Programa de Mobilização da Indústria do Petróleo e Gás Natural). Projeto E&P 27.5 – Métricas de Desempenho da Indústria Nacional. Padrões de Métricas da Indústria EPC Nacional. 2010.

[21] RODRIGUES, V.V. Modelo de Análise de Risco Aplicado a Estudos de Viabilidade para Construção e Incorporação de Prédios Residenciais. Niterói, 2001. 220 p. Dissertação (Mestrado em Engenharia Civil) – Programa de Pós-Graduação em Engenharia Civil, Universidade Federal Fluminense, Niterói. 2001.

[22] ROYALL, R.M. Statistical evidence: a likelihood paradygm. Boca Ranton: Chapman & Hall/CRC, 1997, 191p.

[23] TIPPER, J.C. A simple method for representing some univariate frequency distributions, with particular application in Monte Carlo-based simulation, Computers & Geosciences 34 (2008), pp 1154–1166. 2008.

[24] TRIOLA, M.F. Introdução à Estatística. 7a. Ed. Rio de Janeiro: LTC, 1999.

[25] ZIO, E.; BARALDI, P.; PATELLI, E. Assessment of the availability of an offshore installation by Monte Carlo simulation, Dipartimento Ingegneria Nucleare, Politecnico di Milano, Milan, Italy, International Journal of Pressure Vessels and Piping 83 (2006), pp 312–320. 2006.

[26] WU, Yun-Fu. Correlated sampling techniques used in Monte Carlo simulation for risk assessment, Nuclear Safety Department, Taiwan Power Company, 242, Roosevelt Road, Section 3, Taipei, Taiwan 100, Republic of China, International Journal of Pressure Vessels and Piping 85 (2008), pp 662–669. 2008.

AUTHORS' BIOGRAPHY

Martins, José Luiz Ferreira (1952-08), Male, was born in Sapelos, Boticas, Portugal. He completed his Doctor of Civil Engineering from Federal Fluminense University, Niterói, Rio de Janeiro, Brazil in the year of 2011. D. Sc. Professor of the Mechanical Engineering Departament and Pos Graduate Program in Industrial Construction at Federal Fluminense University. Areas of interest: welding, industrial construction, civil and mechanical engineering, productivity and research methodology.

Ferreira, Miguel Luiz Ribeiro (1953-04), Male, was born in São Gonçalo City, Rio de Janeiro States, Brazil, D, Sc. Professor. He completed his Doctor of Industrial Engineering from São Paulo University, São Paulo, Brazil in the year of 1998. He has been working as a professor and engineer in the field of Industrial Construction for 36 years. He currently develops projects of research in welding, risk analysis in construction and construction productivity mainly focused in process plants of oil and gas industry.

Morano, Cássia Andréa Ruotolo (1968-05), Female, was born in São Paulo City, Brazil. Brazilian nationality. She is D. Sc. Assistant Professor of Pos Graduate Program in Industrial Construction at Federal Fluminense University. She is Architect and Urban Planner graduated from the Federal of Rio de Janeiro University. She completed a master's degree in Civil Engineering in 2003 and his doctorate in Civil Engineering in 2013 from Federal Fluminense University. Areas of interest: risk analysis on projects, industrial construction, civil engineering, productivity and research methodology.