SYSTEMS & MANAGEMENT
Electronic magazine

EVALUATION OF THE IMPACT FACTORS IN THE WELDING PRODUCTIVITY OF INDUSTRIAL PIPES WITH THE MONTE CARLO METHOD

Alexandre Luis Souza Gioia
enggioia@yahoo.com.br
Fluminense Federal Universidade–UFF, Niterói, Rio de Janeiro, Brazil.

Miguel Luiz Ribeiro Ferreira
miguelluiz@id.uff.br
Fluminense Federal Universidade–UFF, Niterói, Rio de Janeiro, Brazil.

ABSTRACT

The objective of this article is the presentation of a method to evaluate the productivity impact factors in the welding of industrial welded carbon steel pipes with the shielded metal arc welding process. The methodology used is based on Monte Carlo simulation and productivity data collected at Petrobras managed works at the Duque de Caxias Refinery (REDUC, acronym in Portuguese). The tool used is the software @Risk6.1 (2013), adapted for evaluation of productivity. This "software" has a resource for the elaboration of the tornado chart, through which the sensitivity analysis is performed, allowing the detection of activities and events with the greatest impact on productivity. The results obtained demonstrate the feasibility of using the method, both for the evaluation of the impact factors on the productivity of the welding procedure, which is called intrinsic productivity, and for the overall productivity, which also considers the unproductive times, where welding is paralyzed as a result of some event. The methodology adopted allows evaluating which activities have the greatest impact on welding productivity, allowing the selection of actions that should be prioritized with a view to their improvement.

Keywords: Impact Factors; Weld Productivity; Industrial Pipes; Monte Carlo Simulation; Sensitivity Analysis.

PROPPI / LATEC
DOI: 10.20985/1980-5160.2019.v14n2.1460

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

1. INTRODUCTION

According to Tabim (2013), welding is the main constructive method in the construction industry of industrial facilities, decisively impacting the quality, cost and term of the works. According to the author, the American Welding Society (AWS) (2002) states that, in the main sectors of the US construction industry, welding represents 13.07% of the total labor cost and 12.10% of the total of the capital expenditures used in the work. In this sense, the monitoring and control of welding productivity are fundamental to ensure the success of an enterprise. Thus, the objective of this article is to evaluate the factors that affect productivity in the welding of industrial pipes of carbon steel. In order to perform this work, a database of welders' productivity in works executed at REDUC was used through the Monte Carlo method, using the @Risk computer program. It should be noted that, with regard to the conceptualization of productivity, two concepts are adopted, namely: intrinsic productivity, which is related to the welding executive procedure, without considering the standstills of the activity for some reason, and global productivity, in which all the events that occur during the welding are considered, accounting for the times of execution and stoppage of the productive process.

2. BIBLIOGRAPHIC REVIEW

2.1 Productivity in construction

Productivity is the main statistical information for the performance of a country, where there are assessments and many other international analogies, being a key source of competitiveness and economic growth in general, according to Durdyev and Ismail (2014), for whom data from activities - productive or otherwise - are very useful for productivity impact research. Shehata and El-Gohary (2012) argue that in the evaluation of productivity, the following models can be used: economic models; specific project models; activity-oriented models; baseline productivity; mile (distance) measure; project management index (PMI); conversion factors; productivity measurement techniques; and difficulties in measuring productivity.

In the studies related to the industrial construction, two main productivity concepts are used: the relationship between the volume of products and goods expressed in monetary value and the number of man-hours consumed in their production; ratio between the volume of goods and assets produced expressed in units of production (tons, m², meters, among others) and the number of man-hours spent in their realization. According to Adrian (2004), which addresses concepts of the United States construction industry, productivity is the result in dollars/man-hours consumed in the production of an enterprise, expressed in US$, as expressed in Equation 1.

$$\text{Productivity} = \frac{\text{Dollars}}{\text{MH consumed}} \tag{1}$$

Source: Adapted by Adrian's authors (2004)

In the Brazilian construction industry, there is a lack of studies on productivity, a scenario that has been modified in recent years. In this sense, Sabóia and Carvalho (1997) record the absence of studies on the subject at the end of the 80's, and in the mid-90's a change of this picture was observed with some debates. It should be noted that, in the case of the Brazilian construction industry, the literature shows that the commonly used productivity indicators are those that relate the quantity of production measured in units (m², tons, meters) by the number of man-hours spent in their execution. This finding can be verified in the research projects: "Industry Performance Metrics", coordinated by Ferreira et al. (2010) and "Mapping of the State of the Art of Construction Technology", in Ferreira (2009), which involved the main engineering and petroleum industry companies in Brazil. According with this concept, Lucariny (2013) proposes the use of the indicator called Unitary Ratio of Production (UPR) for monitoring productivity in enterprises. In this case, the OR is the ratio of the human resources used in certain activities to the number of services performed. Equation 2 demonstrates how UPR is calculated in enterprises:

$$UPR = \frac{\text{Amount of resources}}{\text{Quantity of services (QS)}} = \frac{\text{Men vs. Time}}{\text{QS}} \tag{2}$$

Where: Number of resources = quantity of workers in time unit;
Quantity of services = services performed effectively.
Source: Prepared from Lucariny (2013)

Lucariny (2013) also highlights the differences between the indicators of the manufacturing industry and construction. In manufacturing, the work environment is controlled, the activities are repetitive and standardized, which does not happen in construction. The use of the UPR indicator in industrial pipeline construction projects is presented as Productivity Management at Petrobras construction projects (*Gestão de Produtividade nas Obras da Petrobras* – GEPOP), a productivity management model, developed on the initiative of Petrobras in conjunction with universities, which aims to achieve improvements in cost management, deadlines and productivity monitoring. The work carried out by Araujo et al. (2011) discusses the use of UPR in works at Petrobras through GEPOP.

In Ferreira et al. (2010), productivity indicators used by contractors active in the construction industry in offshore platforms projects are presented. In this work, productivity

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

indicators that cover the enterprise as a whole and others that deal with specific activities, such as welding, painting, thermal insulation, among others are presented. In the case of welding, the established productivity indicator is the unit MH/cm³, which represents the number of man-hours consumed in the deposition of 1cm³ of weld, including welders, assistants and supervisors of the first level of the hierarchical scale. In this sense, as the focus of this paper is the indicators practiced by the construction industry in welding, the productivity indicator adopted reflects the amount of MH consumed in the deposition of 1cm³ of weld, which corresponds to the unit MH/cm³. This indicator was also used in Gioia e Silva (2007), Martins (2011) and Tabim (2013), according to Equation 3:

$$\text{Productivity} = \frac{\text{Man} - \text{hour (MH)}}{\text{Welding volume (cm}^3\text{)}} \quad (3)$$

Where: Men-hour=amount of MH consumed in productive activity or not (global productivity);

MH-hours=amount of MH consumed in the welding activity without considering unproductive times (intrinsic productivity);

Welding volume=amount of solder in volume in unit cm³.

In the development of this article, two productivity concepts were adopted: Intrinsic Productivity (IP) and Global Productivity (GP). IP was defined as that which concerns exclusively the productive process; however, unproductive times, in which no activity is performed, are not considered. In the elaboration of this indicator, the quantities of MH consumed exclusively in welding are recorded: grinding and cleaning of all passes, root, filling, and finishing. In the case of GP, all values of MH, productive or not, consumed for the welding in quantity of volume in the period of accomplishment of the joint are counted. Thus, this indicator measures both the times consumed in the realization of welding and the periods in which the production process was interrupted, such as, for example, personnel displacement, shutdowns, occurrence of rain, lack of material, among other reasons. Equation 3 demonstrates the calculation of GP, considering the total amount of MH spent, whether productive or not.

2.2 Factors affecting productivity in construction

Hasan et al. (2018) have developed a work involving studies carried out in countries of four continents on productivity impact factors in the construction industry in the last 30 years, and they recorded that the most cited factors are: failure to supply materials, inadequate supervision, low workforce capability, inadequate tools and equipment, incomplete drawings and specifications, inadequate communication, rework, inadequate site layout, adverse weather conditions, and design modifications. Dixit et al. (2018) carried out a similar study, covering articles published between 2006 and 2017, reaching very similar results. Goodrum et al. (2011), in a research carried out through statistical analysis of historical data of works carried out, record the main events that generate unproductivity: labor availability, material flow management, schedule control, contractors organizational system and information flow in the enterprise. Liu et al. (2014) conclude that the main factors of productivity impact are: climate, acceleration of activities to recover delays, management of equipment, and low utilization of the concept of constructability. Choi and Ryu (2015) carried out a survey, concluding that the main factors that affect productivity in construction are: climate, location of the enterprise, management failure and failure with materials. Olugboyega (2015) carried out a bibliographical research on the subject, arriving at the results: delays of previous activities; allocation of inefficient space; poor workforce productivity; inadequate or insufficient equipment; delay in information flow, and shutdowns due to weather conditions. A case study conducted by Bass and Hoover (2015) records the following occurrences of ineffectiveness: rework, lack of optimization of tasks, poor planning in equipment and material management, and project management failure. Bierman et al. (2016), in survey-type study applied to professionals working in construction, point the following issues as factors that impact productivity: labor, management failure, characteristics of the place of accomplishment, climate, failure to monitor the consultant (representative of the contractor), tools and equipment. It should be noted that all the factors cited in the mentioned works can be grouped, as proposed by Adrian (2004), as follows: industry-related factors, labor-related causes and management-related factors.

In order to mitigate the factors that reduce productivity, Affonso Neto et al. (2018) suggest the adoption of a methodology based on standardization of tasks, which reduces the occurrence of random events that can generate unproductive times during the working day.

There are also studies that deal with the impact factors of the work environment on workers' performance, which are related to aspects of their physical and mental health. In this regard, Adrian (2004) lists the following points, which may affect workers' performance: physical capacity to perform work, adverse environmental conditions, work continuity, changes in project logistics, and human and subjective factors. Still with the same focus, Moselhi and Khan (2012) conducted research combining three types of techniques, namely: neural networks, regression analysis and fuzzy logic. The results of the research presented as main factors of productivity impact: temperature, relative humidity, precipitation, wind speed, team size, team composition, work type, service height, and service method. It is emphasized that this approach is important; however, it is not the scope of this article.

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

2.3 Using the Monte Carlo method

It is observed in the literature that the Monte Carlo method is used in several situations and is widely used in risk analysis, as in Macêdo et al. (2018). It is highlighted that this method is related as one of the most important tools in risk analysis, according to the PMBOK PMI Guide (2009), which is one of the most important project management models of the present time. The method is based on generating random numbers from an actual database. Regarding productivity, Cho et al. (2017) used the Monte Carlo simulation to evaluate the productivity of concrete slabs with satisfactory results. Woo (2016) adopts this method in the evaluation of the effect of overtime on productivity, evaluating working hours of 50 and 60 hours a week, compared to the traditional 40 hours. In Pradhan and Akinci (2012), the methodology is used to develop studies on productivity monitoring in planning works. Ney (2016) adopts the Monte Carlo simulation to evaluate the behavior of the Labor Rating Factor and the idleness of welders in a pipe factory.

2.4 Sensitivity analysis

It is a tool that can be used in many circumstances, among which, the risk analysis in projects stands out. Still in the context of risk analysis in projects, the works of Sousa et al. (2018) and Jovanovic (1999) point out that the use of sensitivity analysis reduces the uncertainty of the impact of uncertainties arising from changes in costs, inputs, investment value and others in the results of a project. Morano (2003) sought to describe the state of the art in the area of risk analysis for construction projects, through an extensive bibliographical research. The author states that this technique allows evaluating the effect of the variation of each element of cost of a project in its final cost. It is also worth noting that among the authors studied in this study, there is a consensus that, in situations in which sensitivity analysis is to be used, it is fundamental that the variables considered in the model developed for the case are independent.

Tabim (2013) used the sensitivity analysis to evaluate the impact of the variables that affect the productivity of the welding of land pipelines, evaluating both the factors that affect GP and IP. In the study of the variables that affect IP, all the times of the activities developed in the welding procedure were counted, namely: welding with open arc, cleaning between passes, and determination of the preheating temperature.

Ney (2016) uses the sensitivity analysis, via tornado chart, to evaluate the impact of the variables that affect the occupation factor of labor and idleness.

3. METHODOLOGY

3.1 Sample

In this study, productivity data were used in the welding of carbon steel pipes, with shielded metal arc welding process of a construction project of an industrial effluent treatment unit of a refinery , which were collected between the months of October 2012 and April 2013. The tubes used were of various thicknesses and diameters, namely:

- Small - 19 to 50 mm (3/4” at Ø2”);
- Median - 63.5 to 304.8 mm (2 ½” at Ø12”);
- Large - above Ø 355.6 mm (14”).

In the same way, the coupling of these tubes used different types of joints. However, in this paper, the appropriate productivity data of full-thickness butt joints. The data collection procedure consisted in accounting for the number of man-hours for the welding discipline, taking into account the times of activity of the workers consumed from the entry into the refinery, through stoppages, times consumed in the welding, as well as the reworking due to the detection of defects in inspected joints. Initially, the data were presented in the UPR unit (in MH/joint), and in this work, the MH/cm³ unit was chosen, according to Equation 4.

$$\text{Productivity} = \frac{\text{Man} - \text{hour (MH)}}{\text{cm}^3} \quad (4)$$

The amount of welding MH in the determination of IP considers the time spent in the activities that involve the welding procedure, that is, the productive times.

In the case of GP, productive and unproductive times are considered, in which welding is paralyzed due to the occurrence of some event.

The appropriation of the MH encompasses the times spent in activities related to the labor involved in welding. In the IP, the activities that make up the executive welding procedure listed in Table 1 were considered. They are: root, filling, finishing, and preparation of the joint. On the other hand, in the case of GP, in addition to the activities that make up the IP, the generation times of unproductive MH are considered, namely: site + support, delay + standstill, mobility + displacement and rework. Table 1 (the data that propitiated this study is found in Gioia’s dissertation, 2015) shows how these activities were grouped, as well as the period in which the data were collected.

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

3.2 Simulation of productivity data

In this work, the Monte Carlo method was used to analyze the behavior of GP and IP, which was also adopted in Martins (2011) and Tabim (2013), with satisfactory results in relation to other statistical methods for productivity analysis. The Monte Carlo method basically consists of the generation of pseudorandom numbers from a generative function from a previously defined real sample and the elaboration of the Probability Density Function (PDF) and Cumulative Density Function (CDF) curves of the model developed.

In the application of this methodology, the program used was @Risk version 6.1 (company Palisade Corporation), which has the capability to perform the sensitivity analysis through the tornado chart, in which it is possible to evaluate the impact of each variable considered in the average of the productivity indicator model studied. The tornado chart is performed after the script mentioned below, with the result presented in the PDFs and CDFs, that is, it is a component of the simulation from which it is extracted, aiming at the analysis – in this case, of sensitivity. With the tornado graph, it is possible to verify the impact of each function used in this simulation. Based on the times considered for IP, GP, and weld volume calculated for each joint, the following script was used: group the collected data into tables, for generation of frequency histogram; define a distribution for PDF and CDF, with a random variable that best represents the sample (which, in this case, was the survey itself); execute the simulations with 1000 iterations; assess whether the number of simulations is satisfactory; after performing the software simulations, generate the PDF and CDF to treat the results; and finally generate tornado graph based on the deviation of the mean for performing the sensitivity analysis, reaching the factors that impact the selected sample.

For the obtained results, in which the sample was the survey itself, the values found in the functions generated the PDFs and CDFs. The difference proved to be within the expected tolerance, which corroborates the use of the Monte Carlo simulation technique with the level of iterations that assume the values that were not adopted in the sample. Tabim (2013) researched in several sources in which the amount of ideal iteration is around 1000; therefore, this work proceeded in the same way. The model used in the simulation to evaluate the behavior of the IP is expressed in Equation 5, where the weld volume is the absolute value (according to the geometric characteristic of the joint) and the denominator is the sum of the functions of the productive tasks.

$$IP = \frac{WV}{\text{f (MH preparation + grinding)} + \text{f (MH root)} + \text{f (MH filling)} + \text{f (MH finishing)}} \quad (5)$$

Where: IP = intrinsic productivity;

WV = welded joint volume expressed in cm³;

MH preparation + grinding = preparation of the pipe bevel, cleaning between weld passes and removal of small defects and / or slag from the welding process;

MH root = welding with open arc in the root pass;

MH filling = welding with open arc in filling passes;

MH finishing = welding with open arc in the finishing passes.

In the case of GP, the model is presented in the Equation (6).

$$GP = \frac{WV}{\begin{array}{c}\text{f(MH preparation + grinding)} + \text{f(MH root)} + \text{f(MH filling)} + \text{f(MH finishing)} + \\ \text{f(MH complete)} + \text{(MH site + support)} + \text{f(MH delay + shutdown)} + \\ \text{f(MH mobility + displacement)} + \text{f(MH rework)}\end{array}} \quad (6)$$

Where: GP = global productivity;

WV = welded joint volume expressed in cm³;

MH preparation + grinding, MH root, MH filling, MH finishing = according to equation 5 above;

MH complete = welding a joint with a single pass;

MH site + support = activities carried out in the support site to the assembly;

MH delay + shutdown = welders waiting for pipe coupling, scaffolding assembly, absence of employees, planning failure, lack of equipment or material, lack of electrical energy, physiological needs, handling of loads, conducting control inspections quality, non-frequent stoppages, proximity to the end of the working day and idle time without justification;

MH mobility + displacement = mobility activities and displacements in the work;

MH rework = activities that generated rework in welded joints.

In the simulation of the models established for GP and IP, the number of 1000 iterations was adopted, with a confidence level of 95%. Likewise, in order to verify the adequacy of the selected generation functions of the variables that compose the studied productivity models, which represent the behavior of the productive and unproductive times, the 3% standard was used for the convergence test, which is a tool available on the software for this purpose. It should be noted that the results obtained in the simulation met the requirements established, and no anomaly was detected via convergence test, which made it unnecessary to make adjustments in one or more selected generator functions for the variables considered in the models studied. Thus, it is possible to conclude that the generative functions established for the variables of the productivity models developed and the number of iterations used allowed obtaining the curves Probability Density Function (PDF) and Cumulative Density Function (CDF) at the significance level set at 95%. In this sense, the elaboration of the tornado graph to perform the sensitivity test to evaluate the impact of each of the variables in the GP and IP models can be used in an adequate way.

4. RESULTS AND DISCUSSION

4.1 Intrinsic Productivity (IP)

Figures 1 and 2 represent, respectively, the PDF and CDF curves, drawn from the resulting Monte Carlo simulation

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

Table 1. Productivity data collected

	Intrinsic Productivity (MH/cm³)					Unproductivity (MH/cm³)			
Period	Root	Filling	Finishing	Joint preparation	Complete	Site + support	Delay + shutdown	Mobility + displacement	Rework
01 to 05/10	0.0103	0.0092	0.0187	0.0159	0.0000	0.0099	0.0630	0.0611	0.0000
08 to 11/10	0.0109	0.0047	0.0096	0.0025	0.0045	0.1020	0.0983	0.0617	0.0000
15 to 19/10	0.0095	0.0035	0.0074	0.0080	0.0000	0.0426	0.0354	0.0460	0.0000
22 to 26/10	0.0090	0.0085	0.0216	0.0207	0.0207	0.2009	0.4560	0.1904	0.0000
29/10 to 2/11	0.0066	0.0073	0.0092	0.0052	0.0000	0.0752	0.0525	0.0548	0.0072
05 to 9/11	0.0224	0.0294	0.0489	0.0201	0.0000	0.2393	0.1446	0.1236	0.0000
12 to 16/11	0.0092	0.0141	0.0153	0.0091	0.0014	0.1517	0.0462	0.0620	0.0238
19 to 23/11	0.0094	0.0117	0.0287	0.0121	0.0072	0.0571	0.0827	0.0845	0.0179
26 to 30/11	0.0111	0.0055	0.0000	0.0031	0.0031	0.0445	0.0536	0.0416	0.0246
03 to 7/12	0.0197	0.0192	0.0360	0.0139	0.0000	0.0396	0.0469	0.1204	0.0000
10 to 14/12	0.0154	0.0000	0.0101	0.0111	0.0021	0.0603	0.0350	0.0773	0.0384
17 to 21/12	0.0103	0.0057	0.0256	0,0091	0.0000	0.2974	0.0539	0.0848	0.0000
31/12 to 04/1/13	0.0103	0.0092	0.0280	0.0135	0.0000	0.0937	0.0896	0.0732	0.0000
07 to 11/1/13	0.0000	0.0000	0.0034	0.0151	0.0641	0.8662	0.3129	0.2653	0.0283
14 to 18/1/13	0.0038	0.0008	0.0024	0.0026	0.0027	0.1089	0.0387	0.0580	0.0302
21 to 25/1/13	0.0076	0.0279	0.0330	0.0182	0.0381	0.2080	0.0807	0.0984	0.0000
28/01 to 01/2/13	0.0187	0.0050	0.0066	0,0098	0.0014	0.0553	0.0284	0.0312	0.0039
04 to 08/2/13	0.0072	0.0022	0.0000	0.0006	0.0016	0.0562	0.0497	0.0294	0.0095
18 to 22/2/13	0.0015	0.0000	0.0024	0.0032	0.0136	0.1163	0.0642	0.0781	0.0332
25/2 to 1/3/13	0.0023	0.0021	0.0102	0.0032	0.0000	0.1477	0.0599	0.0883	0.0227
04 to 08/3/13	0.0000	0.0000	0.0294	0.0033	0.0000	0.2872	0.2931	0.2035	0.0316
18 to 22/3/13	0.0112	0.0078	0.0218	0.0105	0.0000	0.2965	0.0171	0.1167	0.0000
25 to 28/3/13	0.0073	0.0040	0.0060	0.0060	0.0033	0.4555	0.0175	0.1657	0.0106
08 to 12/4/13	0.0041	0.0024	0.0061	0.0020	0.0004	0.0262	0.0324	0.0707	0.0425

Source: Authors

data of the model developed for IP. Figure 1 shows the PDF developed for IP according to Equation (5) and the CDF is represented in Figure 2. In these figures, the PDF and CDF curves generated by the sample data are represented in blue and those obtained by simulation, in red, and they are superimposed. The values of the coordinates of the 'x' axis are displayed in MH/cm³ and, on the 'y' axis, their probability in fraction. Table 2 shows the main statistics of the sample used in the study development and the simulation data generated from it.

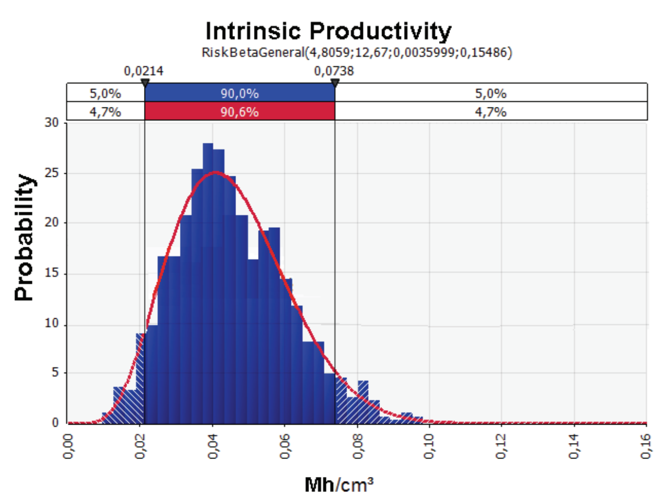

Figure 1. PDF of intrinsic productivity

Source: Authors

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

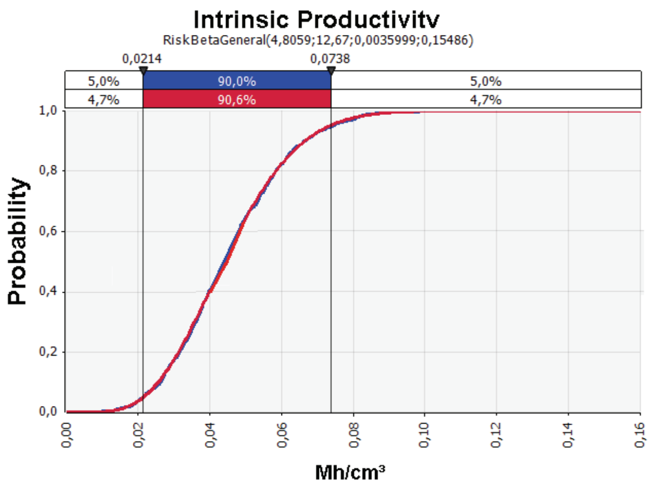

Figure 2. CDF of intrinsic productivity
Source: Authors

It can be observed that the statistics of the sample and those obtained by simulation are very close, which indicates that the generative functions selected to describe the behavior of the variables considered in the IP model expressed in Equation (5) are adequate, since, otherwise, the results would be discrepant. On the other hand, it is important to highlight that the dispersion represented by the coefficient of variation of 0.35, in the sample and in the virtual data generated by simulation, has great influence of the MH variable of preparation/grinding, considering that it involves activities of differentiated nature, which increases the degree of uncertainty. In this case, in order to reduce dispersion, it is advisable to separately record the activities times that are grouped in this activity, namely: preparation of the pipe bevel, cleaning between weld passes and removal of small defects and/or slag. It is expected that this measure reduces the dispersion associated to this variable, since the times that would be counted are related to activities of the same nature.

Another point to note is that, in the elaboration of estimates and procedures of productivity monitoring based on these models, the use of the extremes of the PDF and CDF curves should be avoided, considering the possible inconsistencies determined by the extreme execution conditions, which, for example, may occur at the beginning and at the end of the work due to the variations imposed by the learning curve and forgetfulness. In the same way, it is observed that it is common practice in industry to use the average productivity in the estimates of the term and budget of the works. However, it can be seen in Table 2 that the highest incidence of IP, represented by Mode, is slightly higher than the average productivity, around 4%. In other conditions, using different welding processes and procedures, this difference may be much more significant at values above or below the mean. Thus, the adoption of average productivity as an indicator of productivity in the elaboration of deadlines and budgets should be viewed with caveats, as it may lead to the elaboration of excessively optimistic or pessimistic estimates. In this sense, the use of the PDF and CDF curves, generated from models that describe the productivity behavior, will allow the elaboration of more consistent estimates.

Table 2. Statistics of collected data and simulation - IP

Statistic data	Sample (MH/cm³)	Simulation (MH/cm³)
Mean	0,045195	0,04555
Mode	0,043478	0,04423
Median	0,043291	0,04519
Standard deviation	0,015735	0,01595
Coefficient of variation (standard deviation/mean)	0,35	0,35

Source: Authors

The assessment of the impact factors in the IP can be performed through the sensitivity analysis, using the tornado chart presented in Figure 3, in which it is possible to observe which activities have the greatest influence. Likewise, Table 3 shows the minimum and maximum impacts in the IP due to the variation of the variables presented in the graph.

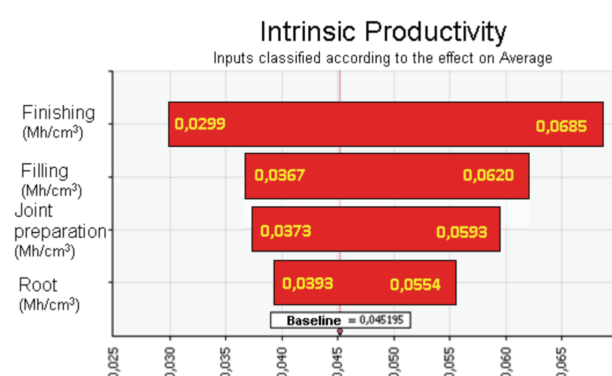

Figure 3. Impact factors on intrinsic productivity
Source: Authors

Table 3. Minimum and maximum impact on IP mean

Activity	Increase (MH/cm³)	Reduction (MH/cm³)	Increase (%)	Reduction (%)
Finishing	0,029911	0,068545	34	52
Filling	0,036728	0,062008	19	37
Preparation / grinding	0,037379	0,059372	17	31
Root	0,039364	0,055433	13	23

Source: Authors

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

When analyzing Figure 3 and Table 3, it can be seen that the filling and finishing phases presented the greatest impact, mainly, in the IP average reduction, reaching 52%. These results are in accordance with the observations described in Tabim (2013), which states that the consumption of MH in the last passes represents the greatest impact on intrinsic productivity. Thus, welding productivity improvement programs should consider actions aimed to increase performance in these phases. As for the finishing phase, this result was expected, given that it is common in industrial works during the finishing phase that the welder tends to pay greater attention to the realization of the last passes, since the visual inspection of weld, which occurs shortly after the joint completion, may lead to joint failure, generating rework. In case of rework, the welder may suffer some type of penalty, in addition to negatively affecting their performance indicators. The impacts of the performance of the other welding variables are within the IP range, represented in Table 2 by the coefficient of variation, in values below 0.35 or 35% of the mean. However, it should be highlighted the impact of the 31% reduction in the productivity of the "preparation/grinding" activity, since this welding phase does not translate into the deposition of weld metal, that is, the amount of weld volume produced. The relevance of the impact of this activity is also recorded in Tabim (2013). It should be noted that the team considered in this work is different, as it is a construction project, and the other, a land pipeline construction. However, the activities that make up the executive welding procedure are similar.

4.2 Global Productivity (GP)

Figure 4 represents the results obtained in the PDF simulation of the behavior of the GP and Figure 5 represents the respective CDF, where the blue curves correspond to the sample data and the curves represented in red correspond to the data obtained by simulation. The values of the coordinates of the 'x' axis are displayed in MH/cm³, and on the 'y' axis, their probability is presented in fraction.

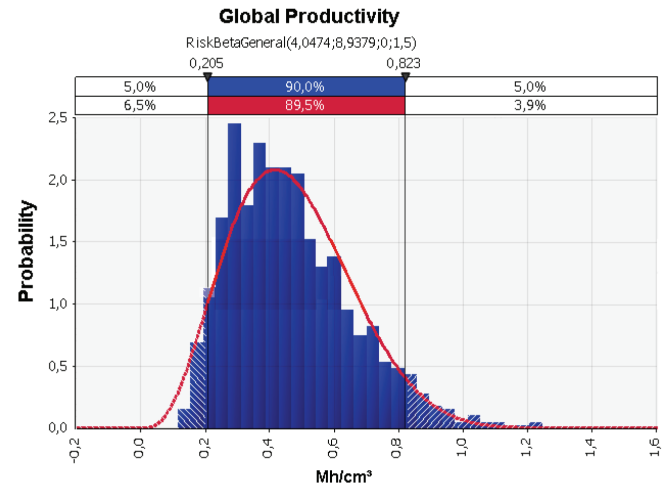

Figure 4. Overall productivity PDF
Source: Authors

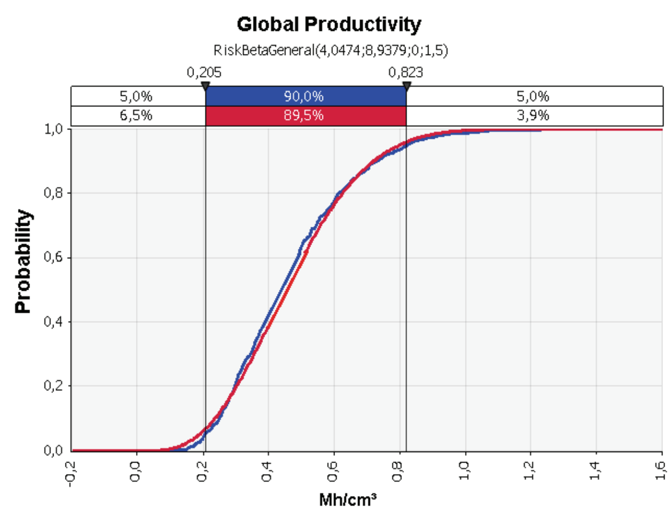

Figura 5. CDF da produtividade global
Source: Authors

The results presented in Table 4 reveal the similarity between the sample data and those developed through the simulation. Thus, it can be stated that the simulation using the Monte Carlo method is an adequate tool for the development of welding productivity studies, a conclusion reached by Martins (2011) and Tabim (2013). On the other hand, when analyzing Table 4, there is a dispersion of 0.41 in the sample and 0.40 in the simulation, expressed by the coefficient of variation, which can be explained by the variety of events grouped in a single variable. In the case of GP, time spent in very heterogeneous activities is recorded much more comprehensively than in the intrinsic productivity model, which is an increasing factor of this dispersion. Similar to the recommendations already presented for the IP model to reduce dispersion, it is advisable to separately

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

record the timing of activities of the same nature. However, the superposition of the CDF curves obtained by the simulation and by the sample data validate the model developed for the evaluation of the global productivity behavior.

As in the IP, in the elaboration of estimates and procedures of productivity monitoring based on these models, the use of the extremes of the curves should be avoided, in view of the possible inconsistencies determined by extreme execution conditions, which may occur at the beginning and at the end of the work by the variations imposed by the learning curve. Likewise, the practice used by industry in adopting the mean of GP in the construction of estimates of the term and budget of the works should be viewed with caution, since the higher incidence of performance, represented by mode, is 24% higher than the mean in the sample and 11% in the simulation. Thus, the evaluation of productivity through the CDF and PDF curves, generated from models that describe the productivity behavior, contributes to the elaboration of more adequate estimates.

In looking at Figures 1, 2, 4, 5 and Tables 2 to 5, it is found that GP is about 10-fold lower than IP when the mean is used as the basis of comparison. When the mode values are compared, these values are, respectively, about 8 times smaller in the sample and 9 in the simulation. It should be noted that the best possible values to be achieved in GP are far from the worst values obtained in the IP. In this case, it is possible to conclude that the variations related to the productivity of the welding procedure and represented by the PDFs and the CDFs of the IP are not significant in relation to those related to the non-productive events. According to Adrian (2004), discoursing on the construction site of the United States, the unproductivity reached 40%. According to Adrian (2004), discoursing on the construction site of the United States, the unproductivity reached 40%. Martins (2011) reveals that, in construction projects of refineries in Brazil, this unproductivity reaches 50%. The results obtained in this study suggest that the unproductivity is much higher than those mentioned in these two studies, which can be better evaluated through the analysis of the factors that contributed to this result.

Table 4. Comparative data, sample data and simulation - GP

Statistical data	Sample (MH/cm^3)	Simulation (MH/cm^3)
Mean	0,4649	0,4675
Mode	0,3554	0,4161
Median	0,437	0,4527
Standard deviation	0,191	0,1858
Coefficient of variation	0,41	0,40

Source: Authors

Figure 6 shows the sensitivity analysis using the tornado chart based on the mean deviation, through which the impacts of each of the events described in this work in the GP were analyzed. In addition, Table 5 presents the minimum and maximum impacts of each of the variables considered in the productivity model developed in the GP average. The analysis of Figure 6 and Table 5 shows that the impacts of the activities related to the execution are much lower than those related to the unproductive times, being within the range of the GP of 0.40, according to the dispersion coefficient presented in Table 4. In this case, in order to evaluate the impacts of the activities that make up the executive welding procedure, with a view to developing actions to improve productivity, it would be more appropriate to use the IP sensitivity analysis discussed in the previous section. This recommendation stems from the fact that the magnitude of unproductive times in relation to productive times, in this case, makes it difficult to detect their impact on GP.

Regarding the unproductivity, when looking at Figure 6 and Table 5, the variables that generate the greatest impact on GP, in order of importance, are: site + support; delay + standstill, and mobilization + displacement. These 3 variables have a significant impact, mainly in the reduction of GP, reaching values of 77% for site + support, 41% for delay + paralysis and 27% for mobilization + displacement.

The variable site + support incorporates the unproductive times related to the following events: small welding repairs, training lectures, safety dialogues, weathering, extra services, strikes and stoppages due to union actions, stops for food and rest during the working day, waiting time for the release of work fronts, shutdowns due to contractor supervision. In this case, it is observed that the methodology of appropriation of unproductive times incorporates very heterogeneous events, which may explain the dispersion observed in GP data, considering that this is the variable with the greatest impact. On the other hand, it is considered the accomplishment of extra services as unproductive time, which is true from the point of view of welding, since the times spent in this case occur with the paralysis of this activity. However, from the enterprise point of view, these times should not be considered as generators of unproductivity.

Because of stoppages due to the times related to welders waiting for pipe coupling, scaffolding, absence of employees, planning failure, lack of equipment or material, lack of electrical energy, physiological needs, load handling, quality control inspections, non-frequent stoppages, proximity to the end of the working day, and idle times without justification, unproductivity is grouped in the variable delay + standstill. As occurs in the variable site + support, the methodology used in the appropriation of unproductive times incorporates very heterogeneous events, which also influences the dispersion observed in the data obtained in

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

the GP, since this is the second variable with the greatest impact. According to Adrian (2004), the unproductive time required to meet workers' human needs at American construction sites is about 15-20% of an eight-hour workday and 40 hours per week. Therefore, if this picture is reproduced in the construction site, object of study of this work, this event would be among the greatest generators of unproductivity, among those grouped in this variable. Thus, due to the importance of its impact on GP, the time spent in this event should be treated separately.

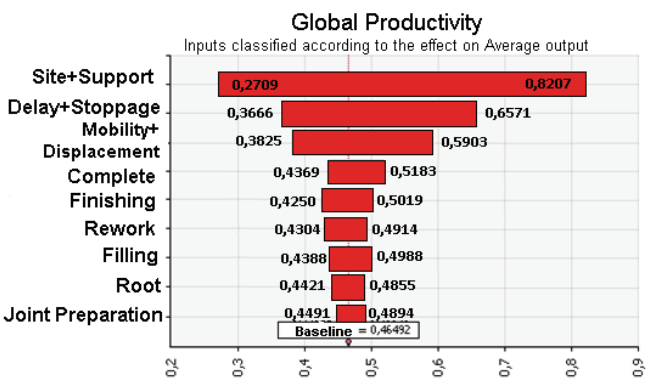

Figure 6. Impact factors in GP
Source: Authors

Table 5. Minimum and maximum impact on the GP average

Activity	Increase (MH/ cm³)	Reduction (MH/ cm³)	Increase (%)	Reduction (%)
Site + support	0,2709	0,8207	42%	77%
Delay + shutdown	0,3666	0,6571	21%	41%
Mobility + displacement	0,3825	0,5903	18%	27%
Complete	0,4369	0,5183	6%	11%
Finishing	0,4250	0,5019	9%	8%
Rework	0,4304	0,4914	7%	6%
Filling	0,4388	0,4988	6%	7%
Root	0,4421	0,4855	5%	4%
Preparation / grinding	0,4491	0,4894	3%	5%

Source: Authors

The variable mobility + displacement represents the times spent due to the mobility characteristics in the refinery, which are as follows: displacement from the main gate to the construction site at the beginning and at the end of the working day, moving the job site at the beginning and at the end of the working day, transportation for lunch and the search of materials from the warehouse to the front of service. Although it has a less significant impact in relation to the site + support and delay + stoppage variables, its variation reaches a 27% reduction in GP, which is an expressive value. This behavior is characteristic of works in which it is necessary that workers travel great distances during the work day, a fact that is also recorded in Tabim (2013).

The rework variable represents the unreliability related to the time spent in the repairs of the welds that were disapproved at the inspection. In this case, the impact of this variable on GP is much lower, compared to the other generators of unproductive times. It should be noted that data were not verified in the literature consulted for purposes of comparison to the results obtained in this work. However, it is possible to conclude that, because the welders in these works are certified and submitted to tests based on international norms, and considering that the welding processes and procedures used are of wide domain, the amount of time spent deriving from the welded joints by non-destructive inspection compared to the rest tend to be low.

Statistical analysis of factors that impact productivity was the subject of studies by Choi and Ryu (2015), where the above analysis corroborates close results. There are factors that demonstrate what can be considered as impact on the result, among which: the effects of location, management, climate and materials. In this study, when there was meteorological interference, the value of the mean of productivity was the one with the greatest impact; however, when associated with management, it was the lowest. It should be noted that the productivity impact factors considered in the database evaluation analyzed in this article are similar to those grouped by Adrian (2004) in two, among the three large groups mentioned previously: factors related to industry, labor-related causes, and management-related factors, also observed in the great majority of the works found in the literature on impact factors in the productivity of the construction industry. However, the influence of workforce aspects on productivity is generally studied in articles in which only this variable is observed. In this article, the database organization did not dwell on these aspects. It is noteworthy that, although the results of the variations of the variables of the global productivity model, used in this work through the tornado chart, demonstrate the potential of using this tool to detect those with greater impact, the clustering of many events and dissimilar activities in a single variable makes it less effective. In this sense, in other works, it is recommended the use of variables that encompass more homogenous events and activities, which will make the results obtained by the sensitivity analysis via the most effective tornado chart. It should be noted that the productivity impact factors related in this article are similar to those mentioned by Hasan *et al.* (2018). However, for the purposes of comparison, the quantification of these impacts is not available in this and other texts found in the literature.

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

5. CONCLUSION

The data obtained in this work allow concluding that the Monte Carlo method is adequate for the evaluation of global and intrinsic productivity behavior, as well as in Tabim (2013) and Martins (2011).

In the development of the simulations developed in this article, both for IP and for GP, it was concluded that the grouping of the times counted in very heterogeneous activities and/or events is not advisable, since it may make it difficult to analyze the results in function of the dispersion produced. In this sense, in the development of productivity models, one must adopt the procedure of grouping and accounting for the productive and unproductive times of events and activities that have the greatest possible similarity, in order to reduce the dispersion of the data generated by simulation.

The use of the sensitivity analysis, through the tornado chart, allows detecting the magnitude of the impact of the activities that make up the executive procedure of the welding in the intrinsic productivity, which allows the development of actions for its improvement.

Regarding the GP, besides the impact of the activities related to the welding procedure, the use of the sensitivity analysis via a tornado chart allows visualizing the events that generate unproductive times. Thus, it is possible to implement a set of actions with the objective of reducing the unproductivity generated by these events.

To improve productivity, Loosemore (2014) explains that improvements in management systematics, such as managerial relationships, application of good engineering practices, modern projects with documentation control, contract management with technical supervision, and use of planning and innovation, are required.

REFERENCES

Adrian, J. J. (2004), Construction Productivity Measurement and Improvement, Bradley University, Stipes Publishing L.L.C., Estados Unidos.

Affonso Neto, A. et al. (2018), “Análise da adoção de práticas LEAN em empresas brasileiras: Um estudo exploratório”, Sistemas & Gestão, Vol. 13, No. 3, pp. 196-208.

Araujo, L. O. C. et al. (2011). “Craft Productivity at Petrobras”, artigo apresentado no Construction Industry Institute: Annual Conference Proceedings, Chicago, Estados Unidos, 25-27 de Jul. 2011.

AWS - American Welding Society (2002), Welding – Related Expenditures and Productivity Measurement in U.S. Manufacturing, Construction, and Mining Industries. 2002.

Bass, D.; Hoover, S. (2015), “Getting the Basics of Construction Productivity Right”, Pipeline & Gas Journal, Vol. 242, No. 11, pp. 63-67.

Bierman, M. et al. (2016), “Productivity management in the South Africa civil construction industry-factors affecting construction productivity”, Journal of the South African Institution of Civil Engineering, Vol. 58, No. 3, pp. 37–44.

Cho, K. et al. (2017), “Effects of Half-Precast Concrete Slab System on Construction Productivity”, Sustainability, Vol. 9, No. 7.

Choi, J.; Ryu H. (2015), “Statistical Analysis of Construction Productivity for Highway Pavement Operations”, KSCE Journal of Civil Engineering, Vol. 19, No. 5, pp. 1193-1202.

Dixit, S. et al. (2018), “Evolution of studies in construction productivity: A systematic literature review (2006–2017)”, Ain Shams Engineering Journal, https://doi.org/10.1016/j.asej.2018.10.010 (acesso em 10 maio 2019).

Durdyev, S.; Ismail, S. (2014), “On-site construction productivity in Malaysian infrastructure projects”, Structural Survey, Vol. 34, No. 4/5, pp. 446-462.

Ferreira, M. L. R. (2009), Relatório do Projeto de Pesquisa “Mapeamento do Estado da Arte da Tecnologia de Construção e Montagem. PROMINP (Programa de Mobilização Nacional da Indústria do Petróleo e Gás Natural), Brasil.

Ferreira, M. L. R. et al. (2010), Relatório do Projeto de Pesquisa “Métricas de Desempenho da Indústria”. PROMINP (Programa de Mobilização Nacional da Indústria do Petróleo e Gás Natural), Brasil.

Gioia, A. L. S. (2015), Fatores de impacto na produtividade em soldagem de tubulação, Dissertação de Mestrado em Montagem Industrial, Universidade Federal Fluminense, Niterói, RJ.

Gioia, A. L. S.; Silva Jr., I. F. (2007), Avaliação de Metodologia para Medição da Produtividade na Atividade de Montagem de Tubulação em Obras Industriais. Monografia Especialização em Montagem Industrial, Universidade Federal Fluminense, Niterói, RJ.

Goodrum, P. M. et al. (2011) “Model to Predict the Impact of a Technology on Construction Productivity”, Journal of Construction Engineering and Management, Vol. 137, No. 9, pp. 678-688.

Hasan, A. et al. (2018) “Factor affecting construction productivity: a 30 year systematic review”, Engineering Construction and Architectural Management. Vol. 25, No. 7, pp. 916-937.

Jovanovic, P. (1999), “Application of sensitivity analysis in investment project evaluation under uncertainty and risk”, International Journal of Project Management, Vol. 17, No. 4, pp 217-22.

Liu, J. et al. (2014), “Validation Methodologies and Their Impact in Construction Productivity Research”, Journal of Cons-

Electronic Journal of Management & System
Volume 11, Number 2, 2019, pp. 142-153
DOI: 10.20985/1980-5160.2019.v14n2.1460

truction Engineering and Management, Vol. 140, No. 10, pp 04014046.

Loosemore, M. (2014), "Improving construction productivity: a subcontractor's perspective", Engineering, Construction and Architectural Management, Vol. 21 No. 3, pp. 245-260.

Lucariny, L. H. (2013). Gestão de empreendimentos: Fatores que influenciam a gestão de prazos na construção pesada, Monografia em Engenharia Civil, Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Macêdo, D. G. et al. (2018), "Determinação do preço assistencial em planos de saúde utilizando simulação", Sistemas & Gestão, Vol. 13, No. 1, pp. 81-87.

Martins, J. L. F. (2011), Aplicação de Simulação com os Métodos de Monte Carlo e Hipercubo Latino na Estimativa da Produtividade no processo de Soldagem por Eletrodo Revestido, Tese de Doutorado em Engenharia Civil, Universidade Federal Fluminense, Niterói, RJ.

Morano, C. A. R. (2003), "Aplicação das Técnicas de Análise de Risco em Projetos de Construção", Dissertação de Mestrado em Engenharia Civil, Universidade Federal Fluminense, Niterói, RJ.

Moselhi, O.; Khan, Z. (2012), "Significance ranking of parameters impacting construction labor productivity", Construction Innovation, Vol. 12, No. 3, pp. 272-296.

Ney, D. C. (2016), Avaliação da metodologia eletrônica para monitoramento do desempenho de soldadores na fabricação de tubulações, Dissertação de Mestrado em Montagem Industrial, Universidade Federal Fluminense, Niterói, RJ.

Olugboyega, O. (2015), "Eliminating Enforced Idleness of Resources and Job Waiting Time in Time-Constrained Construction Activities Using Waiting Line Theory", Journal of Construction Project Management and Innovation, Vol. 5, No. 2, pp. 1196-1210.

PMI – Project Management Institute (2009), "Um Guia do Conhecimento do Gerenciamento de Projetos (Guia PMBOK)", Project Management Institute, 4 Ed., Estados Unidos.

Pradhan, A.; Akinci, B. (2012), "Planning-Based Approach for Fusing Data from Multiple Sources for Construction Productivity Monitoring", Journal of Construction Engineering and Management, Vol. 26, No. 4, pp. 530-540.

Sabóia, J.; Carvalho, P. G. M. (1997), "Produtividade na Indústria Brasileira – Questões Metodológicas e Análise Empírica", artigo apresentado para discussões no IPEA (Instituto de Pesquisa Econômica Aplicada, Brasília, DF, Agosto de 1997.

Shehata, M. E.; El-Gohary, K. M. (2012), "Towards improving construction labor productivity and project's performance", Alexandria Engineering Journal, No. 50, pp. 321–330.

Sousa, B. C. S. et al. (2018), "Priorização de projetos de melhoria de produtividade do método multicritério PROMÉTHÉE II", Pesquisa Operacional para o Desenvolvimento, Vol. 10, No. 1, pp. 27-40.

Tabim, P. M. (2013), Estimativa de produtividade na soldagem de dutos terrestres com aplicação de simulação de Monte Carlo, Dissertação de Mestrado em Engenharia Civil, Universidade Federal Fluminense, Niterói, RJ.

Woo, S. (2016), "Simulation Analysis of Labor Performance during Overtime and Impact on Project Duration", KSCE Journal of Civil Engineering, Vol. 20, No. 7, pp. 2614-2623.

Received: October 05, 2018

Approved: May 15, 2019

DOI: 10.20985/1980-5160.2019.v14n2.1460

How to cite: Gioia, A. L. S.; Ferreira, M. L. R. (2019), "Evaluation of the impact factors in the welding productivity of industrial pipes with the Monte Carlo method", Sistemas & Gestão, Vol. 14, No. 2, pp. 142-153, available from: http://www.revistasg.uff.br/index.php/sg/article/view/1460 (access day abbreviation month year).