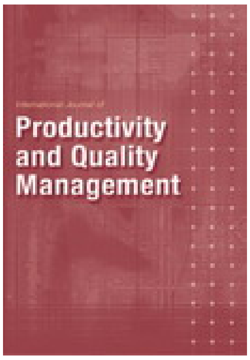
INDERSCIENCE PUBLISHERS
Linking academia, business and industry through research



International Journal of Productivity and Quality Management

ISSN online: 1746-6482 - ISSN print: 1746-6474
https://www.inderscience.com/ijpqm

Model for estimating productivity for the manufacture of aluminium formworks used for the construction of housing with the concrete wall constructive method

Ricardo Chagas Tolentino, Miguel Luiz Ribeiro Ferreira

DOI: 10.1504/IJPQM.2021.10041521

Article History:

Received:	28 December 2020
Accepted:	08 May 2021
Published online:	27 January 2023

Model for estimating productivity for the manufacture of aluminium formworks used for the construction of housing with the concrete wall constructive method

Ricardo Chagas Tolentino* and
Miguel Luiz Ribeiro Ferreira

Fluminense Federal University,
Niterói, Rio de Janeiro, Brazil
Email: ricardotolentino@id.uff.br
Email: miguelluiz@id.uff.br
*Corresponding author

Abstract: In this article, the feasibility of using a model of estimating overall productivity in the production of aluminium formworks in a factory located in the City of Rio de Janeiro, Brazil, for the building of popular housing 'my home, my life' program developed by the Brazilian Government is evaluated. It stands out, that the concept of overall productivity, considers the productive and unproductive times, when production is stopped for some reason. The proposed model is composed of the process productivity and idleness functions. Process productivity involves all production activities of the products studied in this article. The idleness function includes all events that cause production to stop at the factory. The data collected during the production were processed via Monte Carlo simulation, using Palisade Corporation's @Risk 7.6.1 software. The results revealed that the proposed model was successful, indicating that it can be used in industry.

Keywords: overall productivity; aluminium formworks; process productivity; unproductive times; idleness; productivity model; productivity estimating; manufacturing productivity; Monte Carlo simulation.

Reference to this paper should be made as follows: Tolentino, R.C. and Ferreira, M.L.R. (2023) 'Model for estimating productivity for the manufacture of aluminium formworks used for the construction of housing with the concrete wall constructive method', *Int. J. Productivity and Quality Management*, Vol. 38, No. 1, pp.98–122.

Biographical notes: Ricardo Chagas Tolentino holds a Degree in Civil Engineering from the Centro Federal de Educação Tecnológica Celso Suckow da Fonseca in 2014, has a specialisation in Structural Engineering from the Centro Universitário Augusto Motta in 2017, specialisation in Appraisals and Expertise Engineering from the Faculdade Cidade Verde in 2018 and specialisation in Supply Engineering from the Faculdade Cidade Verde in 2019. He is currently pursuing a Master's in Industrial Construction at the Fluminense Federal University (UFF), Brazil.

Miguel Luiz Ribeiro Ferreira is a Metallurgical Engineer from the Fluminense Federal University (UFF), Brazil, Master of Science in Metallurgical and Materials Engineering from the Federal University of Rio de Janeiro (COPPE-UFRJ), Brazil, and Doctor of Sciences from the University of São Paulo (USP), Brazil. During his doctorate course at the USP, he accomplished a research internship at Cranfield University, UK. He has been working for 42 years as an engineer, Professor and researcher in the area of construction of industrial facilities, mainly marine platforms and process plants in the petrochemical, chemical, nuclear, and cellulose industries.

1 Introduction

The concept of productivity is an important performance indicator, but this term is often misunderstood, inadequately measured, compromising its use (Berlak et al., 2021). Improving productivity is a prime factor for the economic growth and wealth of any nation, contributing to better wages, higher profits, and cheaper items, benefiting society (Vogl and Abdel-Wahab, 2015). According to Fu et al. (2021), construction productivity is a key indicator in assessing the efficiency of the production process. Regarding construction industry, productivity improvement may play a fundamental role in a country's economic growth (Nasirzadeh et al., 2020). Thus, measuring productivity has been a substance of debate in the construction industry, mainly due to concerns about accuracy, repeatability and unbiasedness (Fini et al., 2021). Construction industry plays an important role in Brazilian development, where productivity is a strategical issue for its development. Thus, the purpose of this article is to evaluate the precision level of a developed model for estimating the productivity in the manufacture of aluminium formwork, used in the construction system of concrete walls onsite from the behaviour knowledge of process productivity (PP) and the idleness, using Monte Carlo method. The model should also be able to assist managers in implementing actions that improve the production process and reduce the workforce idleness. The study was carried out in a Brazilian company that manufactures aluminium formwork for concrete structures, which was a supplier to construction companies that built popular houses for Brazilian Government program 'my home, my life'. This program started in 2009 aiming to make affordable houses for low-income families (Soares et al., 2013). Due to the need to meeting the construction industry demand, when launching this program, initiatives were implemented to seek innovations to build the housing in the shortest possible time interval, in an economic and safe way, without compromising the quality and performance of constructions. Thus, the system of concrete walls with standards defined by ABNT (2012) was adopted. It should be noted that it is possible to use metal formwork for the construction of popular housing, since it is a feasible cost for large-scale construction. Currently, in the Brazilian market, the formworks are produced in standard sizes, being possible to make them according to each customer's need (Da Silva et al., 2010).

2 Literature review

2.1 Productivity concepts

Scholars such as Nasirzadeh et al. (2020), Durdyev et al. (2018), Barreto (2017), Ney (2016), Tabim (2013) and Adrian (2004) have presented a general and common definition of productivity that is the relationship between the quantity of inputs or production factors in products or services resulted of a production process.

Construction productivity is usually measured based on the relationship between the hours consumed in the construction tasks and the amount of physical results produced, for example, area or tons of installed components (Fini et al., 2021). Productivity indicator measure the effectiveness of production factors used to produce goods and services, and may be compared, both among different periods and among different production units (Sasseron and Nakabashi, 2018). The Construction Industry Institute states that labour productivity is the most widely used performance indicator to assess the success of a venture (CII, 2006). On the other hand, many operations for the construction industry are affected through intense manual labour, and therefore, researchers consider labour force productivity to be one of the best indicators of productive efficiency (Mani et al., 2017). Among the various definitions of labour productivity in the construction industry sector, those that relate the hours of work required to perform an activity over a period, are the most used (Woo, 2016). According to Tabim et al. (2016) productivity is measured through equation (1):

$$Productivity = \frac{Man - hours}{Service\ amount} \tag{1}$$

Scholars such as Barreto (2017), Gióia (2015), Lobato (2015), Tabim (2013), Martins (2011) and Ferreira et al. (2010, 2009) have adopted two concepts of productivity: PP, which is related to the executive procedure and disregards the intervals of activity stoppage for some reason, and overall productivity, which considers all the events that occur during production, accounting for the execution times and stoppage of the production process.

For Hickson and Ellis (2014) the labour productivity is a complex variable to measure. The authors proposed a comprehensive understanding for productivity concept: "production dollars per person-hour of incoming work", and "the amount of work produced per person-hour, equipment-hour or team hour".

According to Martins (2011), the unit ratio of production (URP) is one of the indicators used in construction. In this indicator, the ratio between inputs and outputs results from the number of employees working and their work hours performed per amount of accomplished services. Depending on period time covered by the adopted indicator or the task under analysis, different types of URP arise. Table 1 presents the summary of the URP definitions by Martins (2011) and Ney (2016).

According to Durdyev et al. (2018), productivity will always be related to efficiency and effectiveness. In this direction, Mani et al. (2017) presented other concepts that absorb the idea of efficiency: real productivity (RP), optimal productivity, and the productivity frontier. These concepts are defined as follows:

- RP: Productivity achieved in the field, covering downtime.
- Optimal productivity: Productivity most likely to occur during the execution of an activity, which makes it possible to compare with RP and assess whether a given project is being carried out within the expected time.
- Productivity frontier: Theoretical maximum productivity, the perfect conditions for performing tasks, where operational and system inefficiencies are ruled out, including: unfavourable weather conditions; workers' compromised health status, absence of workers due to health reasons.

Another important concept of productivity is 'baseline productivity'. According Shehata and El-Gohary (2011), 'baseline productivity' corresponds to the best work conditions which is possible to occur in a work environment.

Table 1 Comparison of URP definitions

URP definitions	*Martins (2011)*	*Ney (2016)*
Daily URP	Ratio referring to the values of man-hour and amount of performed service in a working day.	In relation to daily production.
Cumulative URP	Ratio applied when the measurement covers a wider period, adding up the daily indicator values when productivity was first measured to the day in question.	In relation to accumulated production over a period of time.
Cyclical URP	Ratio used when a shorter period than the previous ones is analysed; this ratio is applied in cases when a specific task must be analysed, such as the construction of a masonry.	In relation to cumulative production during a pre-established cycle.
Potential URP	It is defined as a daily URP value meaning good performance and is achievable based on the collected URP values.	In relation to the median of daily URP values that are lower than the cumulative URP.

2.2 Productivity impact factors

According to El-Gohary and Aziz (2014), labour productivity is vital for the profitability of most construction projects. However, many sectors of the construction industry have faced chronic problems such as poor management, substandard working conditions, and insufficient quality, which are events that reduce productivity and should be addressed.

Several researchers have tried to determine the factor that affects construction productivity and from these studies it is possible to observe several factors that cause inefficiencies. Nevertheless, there is no consensus among them, because each activity of the construction process has specific characteristics and that may vary according to each work environment (Hasan et al., 2018).

The lack of standards and reduced productivity contribute to increased costs and deadlines in construction projects (Adrian, 2004). Thus, it is necessary to adopt a methodology based on tasks standardisation to minimise the occurrence of events that might generate idleness during the working hours (Neto et al., 2018). Therefore, the identification of factors impacting construction productivity is of utmost importance. On the other hand, the construction industry is highly fragmented and composed of several stages. In this sense, the stages coordination of the production process is vital for the success of a construction project. This coordination involves: execution of the construction project, preparation of the planning, construction itself and inspections, occupation, operation, and maintenance process. However, the administrative procedures in these stages are a problem for the construction industry, because it can cause interruptions or delays (Durdyev and Ismail, 2016).

Among the factors mentioned by some authors, which impact on construction productivity, it is possible to mention:

- adoption of overtime, according to author (Woo, 2016)
- workers' strikes and lack of qualified professionals (Bierman et al., 2016)
- climatic conditions that directly affect the productivity of construction workers, from a physiological and psychological point of view (Ibbs and Sun, 2017)
- heavy and manual work is more tiresome and in the works with these activities, workers suffer productivity degradation more quickly, than those who perform lighter and less exhausting activities (Ibbs and Sun, 2017)
- the highest productivity values are probably affected depending on the region where a worker is performing his activities (Ibbs and Sun, 2017)
- lack of materials; equipment breakdown; lack of inadequate tools and equipment; scope modification (Rad and Kim, 2018)
- lack of communication with the internal management team (Vaux and Kirk, 2018)
- accidents at construction sites (Li et al., 2021).

Ney and Ferreira (2018), in an article about manufacturing of spool pipes, have considered idleness and waiting times as important factors for assessing total idleness. Therefore, it should be considered that when employees are idle or performing out-of-duty activities in the productive process, the action is classified as unproductive, reducing productivity.

Abellana (2020) adopted the 'interpretative structural modelling (ISM)' technique to analyse the relationships between the factors that impact the productivity and quality of automotive repair services. The author concluded that the main factors which reduce productivity are related to lack of management.

2.3 Productivity estimating methodologies

Raoufi and Fayek (2020) developed a methodology based on fuzzy and Monte Carlo methods, which aims to complement the technique: 'agent-based modelling (ABM)', to analyse productivity and practices used in the construction industry.

Fayek (2020) argues that productivity modelling based on Logica fuzzy has been widely used in the construction industry, however, researchers are adapting this technique associated with other models to obtain more accurate results.

Agarwal and Mehrotra (2020) used the data envelopment (DEA) technique as a tool for estimating and monitoring productivity to compare performance between some of India's leading retail companies. The study aimed to show the performance of the production process and to identify the possible reasons for the detected inefficiencies.

Motlagh et al. (2020), have developed a qualitative model for estimating and monitoring productivity, which called: 'fuzzy analytic hierarchy process (FAHP)', in order to assess the efficiency and effectiveness of a leading service company of internet in Iran.

Nasirzadeh et al. (2020) proposed the adoption of a method based on artificial neural networks to monitor and estimate productivity, based on historical data and, according to authors, with satisfactory results.

Golnaraghi et al. (2020) evaluated the utilisation of the method ‘evolutionary polynomial regression (EPR)’ in modelling productivity for the installation of moulds in the construction industry, which has been used successfully. The authors compared the results obtained using this method with three others: best subset, stepwise, and general regression neural network (GRNN). The research results showed that EPR method presented better solutions for nonlinear systems and based on statistical data of performance indicators.

It is observed in the literature that Monte Carlo method has been applied to analyse and estimate productivity (Ney and Ferreira, 2018; Barreto, 2017; Gióia, 2015; Lobato, 2015; Martins and Ferreira, 2013; Tabim, 2013). Gurmu and Ongkowijoyo (2020), developed a model to monitor and estimate baseline productivity of workforce based on Monte Carlo method. According to the authors, the model showed good results in operations involving buildings that use wooden formworks. Tabim (2013) developed work with the use of @Risk 6.0 software to study the behaviour of PP and global in the welding of terrestrial pipelines. The cumulative distribution functions (CDFs) curves made it possible to observe the performance possibilities and the probabilities of occurrence of the PP values and for the overall productivity. In this study, with the use of Monte Carlo method and the resources of the software @Risk 6.0, it was possible to estimate the productivity loss in production process’ activities due to occurrence of events that generated unproductive times. Lobato (2015) adopted Monte Carlo method as a tool to evaluate the welding productivity behaviour of ASTM a-36 steel with electrode E71T-1C/M and two protective gases: ArC-25 (75% argon and 25% CO_2) and ArC-40 (60% argon and 40% CO_2). The author used Monte Carlo method through @Risk 7.5 software, and from the simulation results it was possible to determine which type of protective gas resulted in welding procedures with higher productivity. Ney and Ferreira (2018) used Monte Carlo method to evaluate the performance of a methodology to evaluate the occupancy factor and the idleness of workers inside a factory, which is a supplier of pipes for industrial pipes construction for marine platform process plants. The obtained results allowed both the determination with reasonable accuracy of the occupancy factor and the idleness in the factory, to establish the events with the greatest impact on the idleness of the workers. Gióia (2015) also adopted Monte Carlo method to evaluate the factors that impact the welding productivity of industrial carbon steel pipes in Works managed by Petrobras at the Duque de Caxias Refinery (REDUC). The author used the computational program @Risk 6.1 to analyse the factors that impacted welding productivity, considering the productive and unproductive times. Martins and Ferreira (2013) evaluated the feasibility of Monte Carlo method application estimating industrial carbon steel pipes welding productivity with tungsten inert gas (TIG) welding process. The experiment results demonstrated the possibility of Monte Carlo method application to estimate industrial pipe welding productivity.

3 Methodology

3.1 Experimental procedure

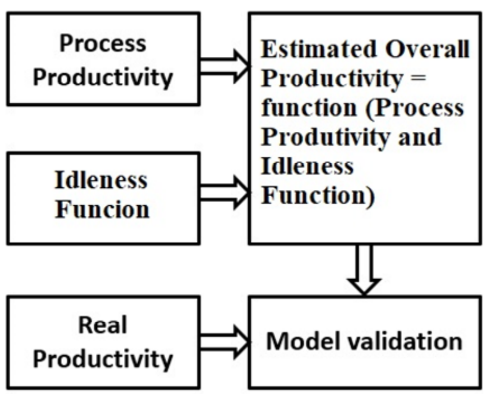
The experimental procedure aims to evaluate whether the proposed model, which is a composite function constructed from the ‘PP’ function and the ‘idleness function (IF)’, is suitable for estimating overall productivity. Overall productivity considers productive and unproductive times in a daily workday. Monte Carlo method was used for data processing of functions that compose this model, obtaining the probability density function and CDF curves. To validate the overall productivity model, one compared the probability density function and CDF curves obtained via Monte Carlo simulation of the model with the 'RP'. 'RP' referred to the productivity data, resulted from 30 days of production noted by field supervision.

Monte Carlo simulation was performed in Microsoft Office Excel and the software @Risk 7.6.1 from Palisade Corporation. The functions submitted to the simulation are described as follows:

- PP – Productivity of the production process, considering all activities, disregarding the events when production is stopped for some reason.
- IF – Percentage of time, in working hours, in which production is stopped for some reason.
- Estimated overall productivity (EOP) – Estimated global productivity function, determined from knowledge of PP and idleness.
- RP – Function built from the daily productivity data appropriated by company.

Figure 1 describes the procedure for carrying out the experiment.

Figure 1 Experiment steps for validation of the overall productivity estimation model



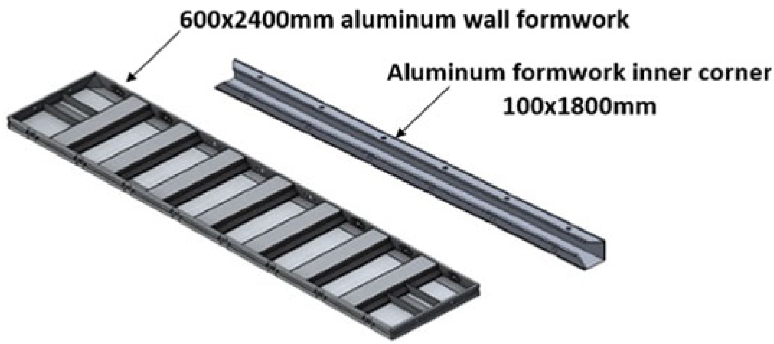
The tornado diagram type deviation of the mean is a resource available in the @Risk 7.6.1 software, which makes it possible to perform the sensitivity analysis, allowing to evaluate and quantify the variables impacts, that make up the function observation object. This resource is used to evaluate the impact factors of the mean over the functions: 'PP', 'IF' and 'EOP'.

3.2 Sample

The sample consists of information and data related to formwork manufacturing productivity for reinforced concrete structures. Data collection was carried out through field observations inside the manufacturing area of a company that manufactures aluminium formwork for the construction industry and that operates throughout Brazil. Two products of the production line were selected: aluminium formwork for wall of

600 × 2,400 mm and aluminium formwork inner corner 100 × 1,800 mm, weighing, respectively 25.50 kg and 7.38 kg, indicated in Figure 2.

Figure 2 Aluminium formworks



The production process activities of the 600 × 2,400 mm shape are: cutting the side profile, cutting the head profile, cutting the rib profile, cutting the aluminium sheet 3.0 mm, cutting the aluminium sheet 2.5 mm, milling the side profile, drilling the side profile, drilling the head profile, installating the bushing and rivet on the side profile, assembling, welding, lining up and throwing and applying lime. Meanwhile, the production process of the inner corner formwork 100 × 1,800 mm consists of: cutting the profile, drilling the profile, milling and performing 45 degree cutting.

3.3 PP model

The PP will be obtained through the weight division of one formwork in kg, by the sum of the probability density function of the amount of man-hour (Mh) taken for each activity, which makes up the production cycle. However, unproductive times, when production was stopped due to some event, are not considered. Probability density functions of activities of the function of 'PP' modelled with assistance of the software @Risk 7.6.1, for the two products, are shown in Tables 2 and 3. Equation (2) represents the function that expresses the behaviour of 'PP':

$$PP = \frac{Piece\ mass\ (kg)}{\sum Probability\ density\ \ function\ (for\ each\ activity)(Mh)} \tag{2}$$

The direct workforce involved in the production process consists of 15 operators and 10 welders. The working hours are from Monday to Friday, the business hours are from 7:00 AM to 5:00 PM and Friday from 7:00 AM to 4:00 PM. Data collection took place in the company's manufacturing area for three months. The amount of Mh for each activity was counted, considering the measurement of the times and the team involved in performing the work. The dataset of Mh determined for each activity, per panel, was 30 observations. It should be noted that in these data collection, dates with atypical schedules or holidays were excluded. The simulation products of this model are: CDF curve, probability density function curve and tornado diagram, for production process of each product.

Table 2 Probability density functions of the activities of the function of ‘PP’ modelled with assistance of the software @Risk 7.6.1 – manufacturing of formworks (600 × 2,400 mm) (see online version for colours)

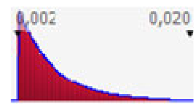
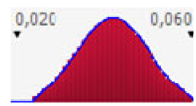
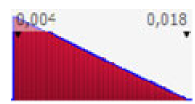
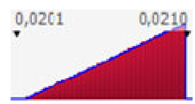
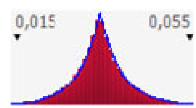
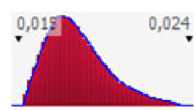
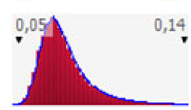
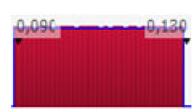
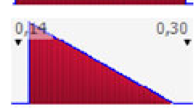
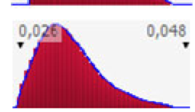
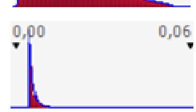
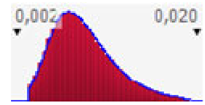
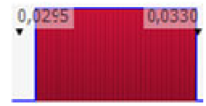
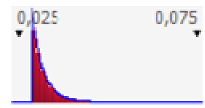
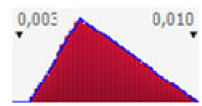
Process activity	*Probability density function*	*Graph*
Cutting the side profile	RiskUniform(0, 0039751; 0, 035747; RiskName(“Cutting the side profile”))	
Cutting the head profile	RiskPareto(1, 8673; 0, 0041667; RiskName(“Cutting the head profile “))	
Cutting the rib profile	RiskExpon(0, 0034444; RiskShift(0, 002663); RiskName(“Cutting the rib profile”))	
Cutting the aluminium sheet 3.0 mm	RiskNormal(0, 0421019; 0, 0075383; RiskName(“Cutting the aluminium sheet 3.0 mm”))	
Cutting the aluminium sheet 2.5 mm	RiskTriang(0, 0041667; 0, 0041667; 0, 017724; RiskName(“Cutting the aluminium sheet 2.5 mm”))	
Milling the side profile	RiskTriang(0, 02017467; 0, 02097222; 0, 02097222; RiskName(“Milling the side profile”))	
Drilling the side profile	RiskLaplace(0, 034444; 0, 0061283; RiskName(“Drilling the side profile”))	
Perforate the profile of the head	RiskExtvalue(0, 0175075; 0, 0012959; RiskName(“Perforate the profile of the head”))	
Installation of the bushing and rivet on the side profile	RiskLoglogistic(0, 053019; 0, 020882; 3, 3143; RiskName(“Installation of the bushing and rivet on the side profile”))	
Assembling	RiskUniform(0, 090441; 0, 128448; RiskName(“Assembling”))	
Welding	RiskTriang(0, 15417; 0, 15417; 0, 28432; RiskName(“Welding”))	
Line up	RiskExtvalue(0, 0311223; 0, 0032452; RiskName(“Line up”))	
Throwing and applying lime	RiskPareto(5, 527; 0, 0061111; RiskName(“Throwing and applying lime”))	

Table 3 Probability density functions of the activities of the function of 'PP' modelled with assistance of the software @Risk 7.6.1 – manufacturing of formworks – inner corner (100 × 1,800 mm) (see online version for colours)

Process activity	*Probability density function*	*Graph*
Cutting the profile	RiskExtvalue(0, 0075323; 0, 0025165; RiskName("Cutting the profile"))	
Drilling the profile	RiskUniform(0, 0299042; 0, 0328736; RiskName("Drilling the profile"))	
Milling	RiskPareto(10, 358; 0, 03; RiskName("Milling"))	
Performing 45 degree cutting	RiskTriang(0, 0036141; 0, 0055556; 0, 0099856; RiskName("Performing 45 degree cutting"))	

3.4 IF model

For the idleness model, the percentage of time in which a worker is stopped, during a daily working day, was used. To process the collected data of idleness with the Monte Carlo method, the 'IF' was adopted, involving all the events that generate idleness, according to equation (3).

$$IF = \sum \textit{Probability density function of the incidence of events "N" that generate idleness} \quad (3)$$

where IF = probability density function of 'IF'; incidence of events *N* = number of occurrences of the event *N*, idleness generator, on a specific day divided per number total de events registered at that date, *N* varies from 1 to 16; event 1 = delay; event 2 = absence; event 3 = search equipment; event 4 = search or replace the personal protection equipment (PPE); event 5 = all of the cleaning and housekeeping of the work area; event 6 = waiting for raw materials; event 7 = interaction of co-workers; event 8 = room, supervision; event 9 = faulty machine; event 10 = waiting for an order of production (OP); event 11 = human needs; event 12 = displacement; event 13 = safety and management meetings; event 14 = lack of energy; event 15 = interruption of the activities due to the movement of loads close to the work station; event 16 = project review – wrong project. Probability density functions of the incidence of the idleness generator events are presented in Table 4.

Table 4 Probability density functions of the events of 'IF' modelled with assistance of the software @Risk 7.6.1 (see online version for colours)

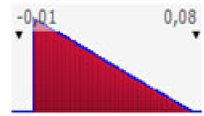
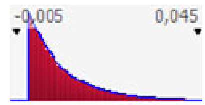
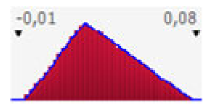
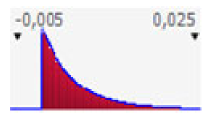
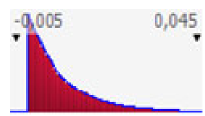
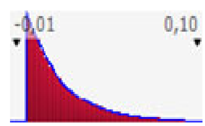
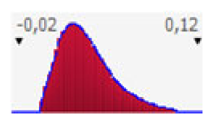
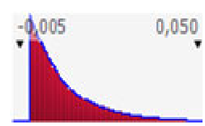
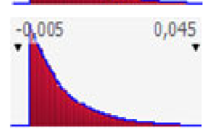
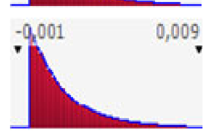
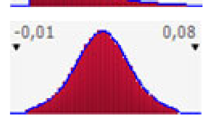
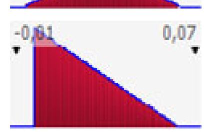
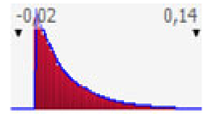
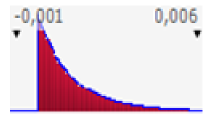
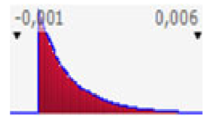
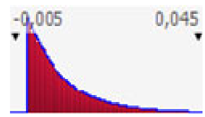
Idleness factors	*Idleness function*	*Graphic*
Delay	RiskTriang(0; 0; 0, 075996; RiskName("Delay"))	
Absence	RiskExpon(0, 0090476; RiskShift(–0, 00020106); RiskName("Absence"))	
Search equipment	RiskTriang(–0, 0039215; 0, 025; 0, 075754; RiskName("Search equipment"))	
Search or replace the PPE	RiskExpon(0, 0049802; RiskShift(–0, 00011067); RiskName("Search or replace the PPE"))	
All of the cleaning and housekeeping of the work area	RiskExpon(0, 0087897; RiskShift(–0, 00019533); RiskName("All of the cleaning and housekeeping of the work area"))	
Waiting for raw materials	RiskExpon(0, 020258; RiskShift(–0, 00045018); RiskName("Waiting for raw materials"))	
Interaction of co-workers	RiskExtvalue(0, 025009; 0, 01674; RiskName("Interaction of co-workers"))	
Room, supervision	RiskExpon(0, 010159; RiskShift(–0, 00022575); RiskName("Room, supervision"))	
Faulty machine	RiskExpon(0, 0089484; RiskShift(–0, 00019885); RiskName("Faulty machine"))	
Waiting for an order of production (OP)	RiskExpon(0, 0018254; RiskShift(–0, 0000405644); RiskName("Waiting for an OP (order of production)"))	
Human needs	RiskLogistic(0, 0339186; 0, 0080804; RiskName("Human needs"))	
Displacement	RiskTriang(0; 0; 0, 060866; RiskName("Displacement"))	

Table 4 Probability density functions of the events of 'IF' modelled with assistance of the software @Risk 7.6.1 (continued) (see online version for colours)

Idleness factors	*Idleness function*	*Graphic*
Safety and management meetings	RiskExpon(0, 026706; RiskShift(–0, 00059347); RiskName("Safety and management meetings"))	
Lack of energy	RiskExpon(0, 00125; RiskShift(–0, 0000277778); RiskName("Lack of energy"))	
Interruption of the activities due to the movement of loads close to the workstation	RiskExpon(0, 0011508; RiskShift(–0, 0000255732); RiskName("Interruption of the activities due to the movement of loads close to the work station"))	
Project review – wrong project	RiskExpon(0, 0092857; RiskShift(–0, 00020635); RiskName("Project review – wrong project"))	

The described events are the factors that cause idleness during the manufacturing process in working hours. The compilation of these events was determined through interviews with factory supervisors which are in line with what was observed in the researched literature. In addition, for idleness observation, 45 days were dedicated to follow the routine of 10 workers inside factory area. The data collecting hours and dates were organised in a table form using Excel software and, every 30 minutes, there were inspections to verify whether the workers were performing the activities of the production process. If they were not, the observer should appoint a note on the worksheet with the reason for idleness. Thus, a total of 160 notes were daily registered from Monday to Thursday and 140 on Friday. It is noteworthy that in these observations, there was no accounting of time, the record of the occurrence is a punctual photograph of the event under analysis. Upon completion of the 45 days of follow-up, a total of 4,720 records were obtained, with 1,184 points representing the 'idleness' situation. Figure 3 presents the model adopted to perform daily registering of idleness situations detected.

The steps for completing Figure 3 are:

1 If the employee is busy (performing some activity of the production flow), mark with an 'x' the field corresponding to the column 'busy' and the line of the observed time.

2 If the employee is idle mark with an 'x' the field corresponding to the column 'idle' and the line of the observed time.

3 In case the idle column is marked, write the item number corresponding to the reason in the appropriate field.

After the idleness data was collected and organised, equation (3) is processed through Monte Carlo simulation, obtaining: tornado diagram and probability density function and CDF curves.

Figure 3 Model for recording observations of daily idleness

Operator No. 1			
hour	Occupied	Idle	Justification
07:00			
07:30			
08:00			
08:30			
09:00			
09:30			
10:00			
10:30			
11:00			
11:30	LUNCH		
12:00			
12:30			
13:00			
13:30			
14:00			
14:30			
15:00	SNACK		
15:30			
16:00			
16:30			
17:00			

Justifications for idleness	
1	Delay
2	Lack
3	Search for equipment
4	Search or exchange personal protective equipment
5	Clean and tidy the work area
6	Wait for raw material
7	Interaction with colleagues
8	Supervision room
9	Defective machine
10	Waiting for production order
11	Human needs
12	Displacements
13	Security and Management Meetings
14	Lack of electricity
15	Interruption of activities due to the movement of loads near the workbench
16	Project review - wrong project

3.5 EOP model

After modelling the PP function and the IF, equation (4) was elaborated for analysing the behaviour of EOP. This function will be submitted to Monte Carlo simulation obtaining: probability density function and CDF curves and tornado diagrams.

$$EOP = \frac{Process\ \ productivity\ (PP)}{1 + Idleness\ \ function\ (IF)} \tag{4}$$

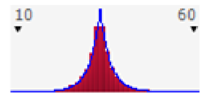
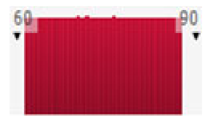
The effectiveness of the model for estimating productivity was evaluated by comparing the results of EOP and 'RP', as described in Subsection 3.1. In this analysis, the results represented by the probability density function and CDF curves of both functions are superimposed. Likewise, the following data of the functions involved in this study were also analysed: mean, mode, standard deviation and coefficient of variation. The adherence of the results obtained by the simulations of these functions, will allow to evaluate the accuracy degree of the EOP model for the manufacture of products studied in this article.

'RP' function was elaborated based on the daily productivity data appropriated by the supervisor for 30 days. The collected data were organised in spreadsheet and represent the daily production and the productive and unproductive times, spent in the whole process to perform the activities. Equation (5) describes the behaviour of 'RP' and expresses the total daily amount of products produced in kg divided by the sum of the appropriate hours of employees to perform the activities that encompass the production process.

$$RP = \textit{Probability density function of daily productivity} \quad (5)$$

where daily productivity = daily production amount (kg) divided by quantity of Mhs consumed. Table 5 presents the probability density functions of the two products.

Table 5 Probability density functions the function 'RP' modelled with assistance of the software @Risk 7.6.1 – manufacturing of formworks (600 × 2,400 mm) and formworks – inner corner (100 × 1,800 mm) (see online version for colours)

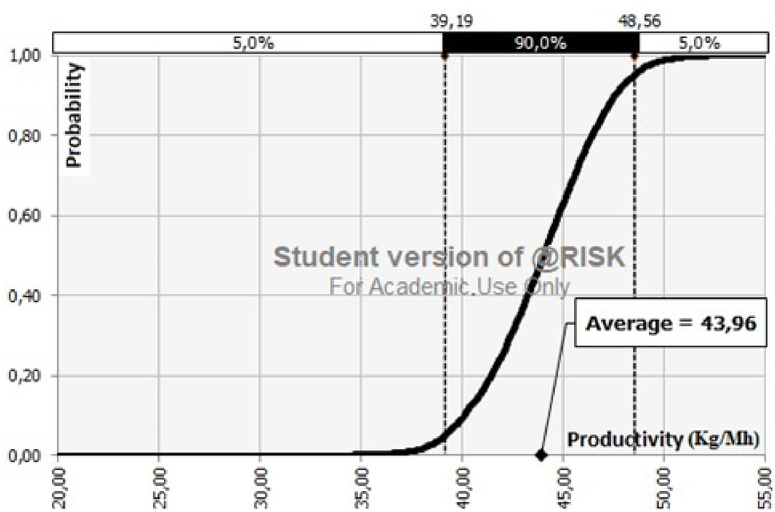
Manufacturing of formworks	*Function of distribution*	*Graphic*
600 × 2,400 mm	RiskLaplace(33, 7213; 3, 7016; RiskName("Real Productivity")	
Inner corner (100 × 1,800 mm)	RiskUniform(62, 169; 87, 188; RiskName("Real Productivity")	

4 Results and discussion

4.1 PP behaviour

Figures 4 and 5 present the CDF curves produced through Monte Carlo simulation of 'PP' of each product, expressed in equation (2). The confidence interval of 5% to 95% in the curve was considered to avoid discrepant values at the end of the graph in order to be as close as possible to the actual results. Table 6 presents the main statistics of the functions obtained via simulation of the 'PP' established for the two products.

Figure 4 Behaviour of CDF of aluminium formworks – PP



Observing Figure 4, it is verified that the PP between 39 to 48 kg/Mh, has 90% probability of occurrence, for the production of aluminium formworks. In the case of aluminium formwork production – inner corner, this range is between 83 and 100 kg/Mh. Unfortunately, no evidences were found in similar products studies. However, 'PP' variability, expressed by coefficient of variation, present low values (Martins, 2011; Tabim, 2013; Lobato, 2015).

Figure 5 Behaviour of CDF of aluminium formworks (inner corner) – PP

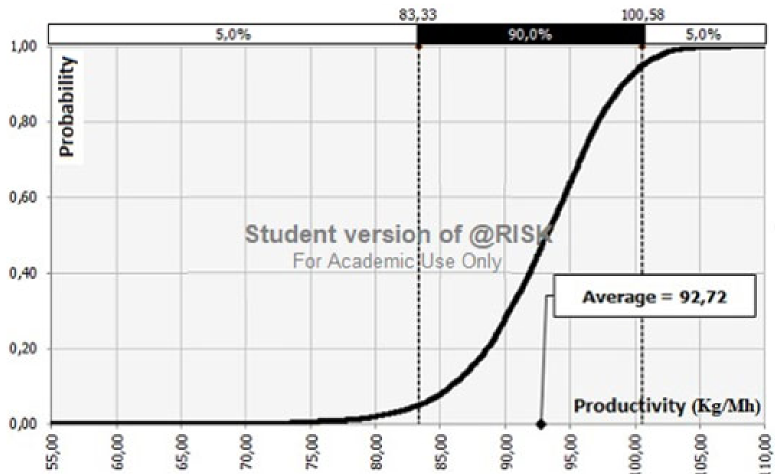
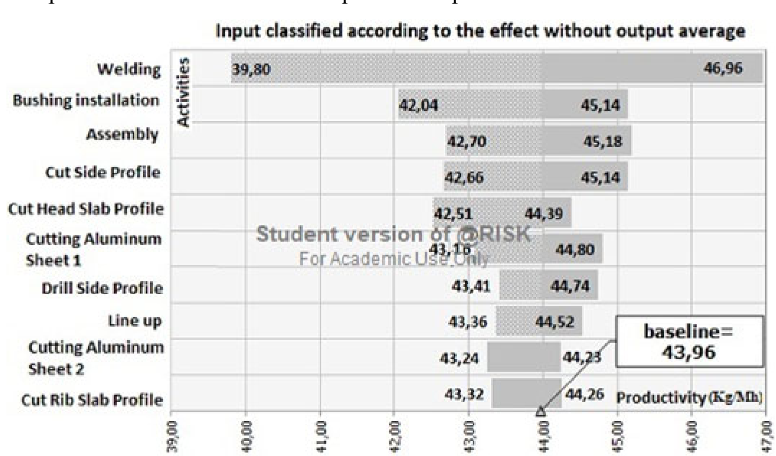


Table 6 Main statistics of probability density function of PP of aluminium formworks and aluminium formworks – inner corner

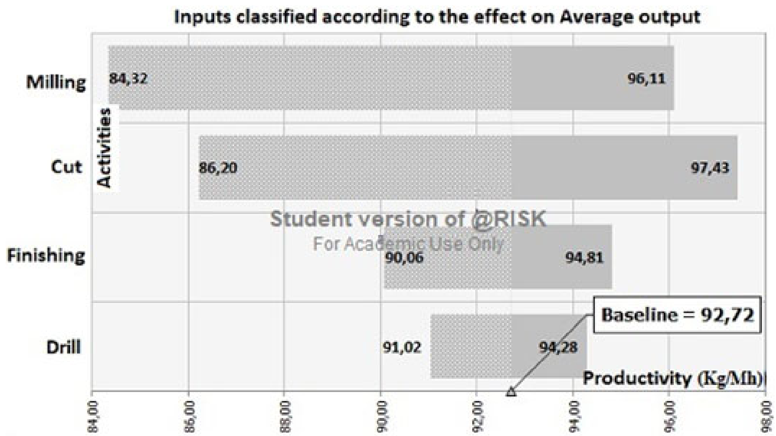
Formwork	*Mean (kg/Mh)*	*Mode (kg/Mh)*	*Standard deviation*	*Coefficient of variation (CV)*
Formwork 600 × 2,400 mm	43.96	45.26	2.92	0.07
Inner corner 100 × 1,800 mm	92.72	94.15	5.34	0.06

Figure 6 Impact of aluminium formworks production process activities on the mean of PP



Figures 6 and 7 present the tornado diagram type deviation of the mean, where one may observe the impacts of the activities of manufacture of both products, over the 'PP' function. Each horizontal bar register the influence level of the fabrication activities over that function. Looking at Figure 6, it is verified that welding is major impact activity, both in reducing and increasing the mean of the 'PP' for the aluminium formwork production. In case of inner corners production, as shown in Figure 7, it is observed that the cutting activity has the greatest influence on the increase in the mean of 'PP'.

Figure 7 Impact of the production process activities of aluminium formworks – inner corner on mean of PP



By analysing the results obtained through the sensitivity analysis, using the tornado diagram, it is possible to identify which activities have the greatest influence on the performance of manufacturing activities, increasing, or reducing productivity. Consequently, production managers will be able to implement and prioritise actions, aiming at improving productivity.

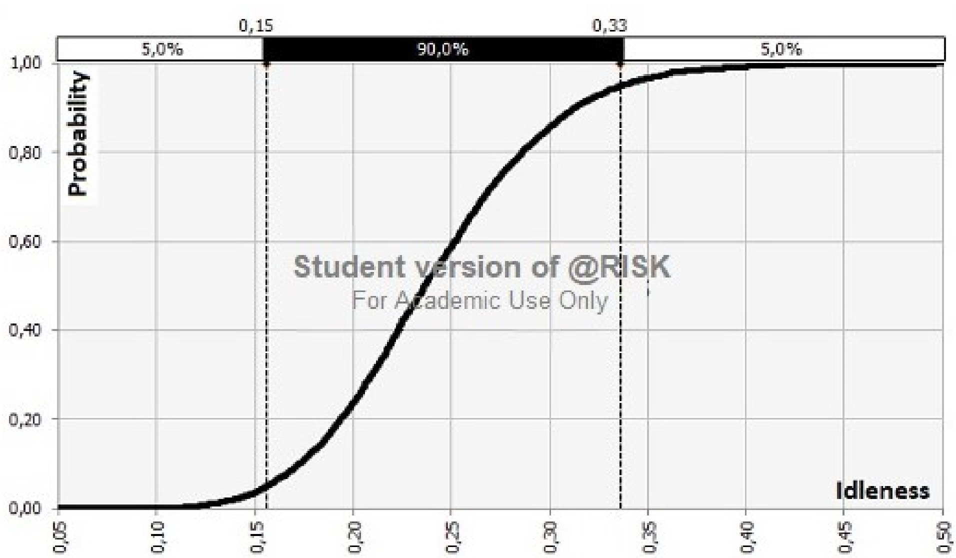
4.2 Behaviour of idleness

To determine idleness, 4,720 points were collected over a period of 45 days. It was observed that in 25.08% of the time, employees are idle for some reason, and in the other 74.92% they are busy and involved with manufacturing process activities. From the collected data, the 'IF' was built, according to the model established in equation (3), submitting the model to Monte Carlo simulation. The curve of the CDF of the 'IF' in Figure 8, and in this case, the confidence interval between 5 and 95% was also adopted. The main statistics of the results of the curve generated via simulation are presented in Table 7. After analysing Table 7, it was verified that the coefficient of variation value is significant, especially when compared to the 'PP' function. This result is similar to those obtained by other researchers (Ney and Ferreira, 2018; Tabim, 2013).

Table 7 Main statistics of the IF

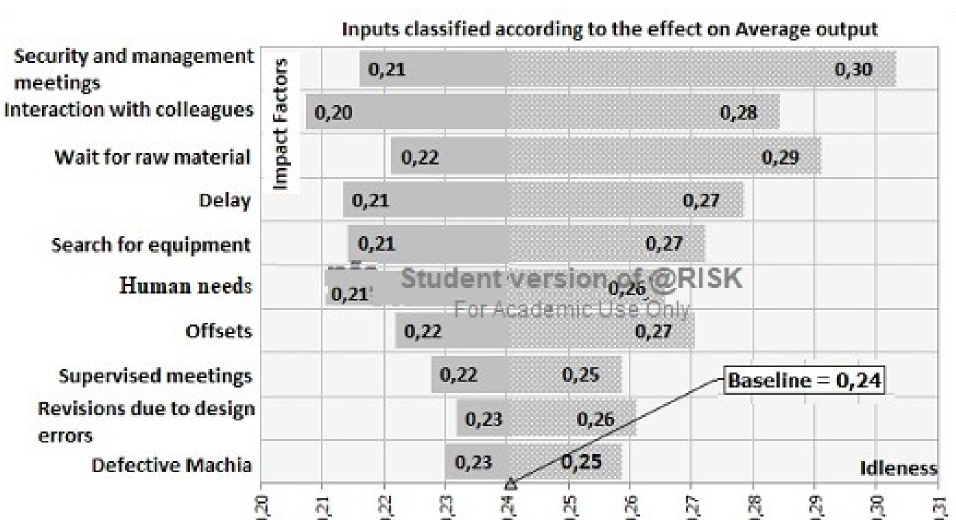
Mean	*Mode*	*Standard deviation*	*Coefficient of variation (CV)*
0.24	0.25	0.05	0.23

Figure 8 Behaviour of the CDF of factory IF



In order to evaluate the impact of each idle generator event of over IF, a sensitivity analysis was performed, using the tornado diagram deviation from the mean, as shown in Figure 9.

Figure 9 Impact of production stoppage events on the mean of factory IF



It is noted that 'security and management meetings' are the main events that increase company idleness and can increase it by up to 30.10%. This result is similar to those recorded by Durdyev et al. (2018), Hickson and Ellis (2014) and El-Gohary and Aziz (2014). It should be mentioned that the impact of the event 'human needs' is similar to the findings of other researchers (Adrian, 2004; Martins, 2011; Ney and Ferreira, 2018). On the other hand, actions on the variable 'interaction between colleagues' produce the greatest reduction in idleness at the factory. The use of the tornado diagram results will allow managers to implement actions aimed at reducing idleness.

Figure 10 Comparison between CDF of EOP and RP of aluminium formworks production

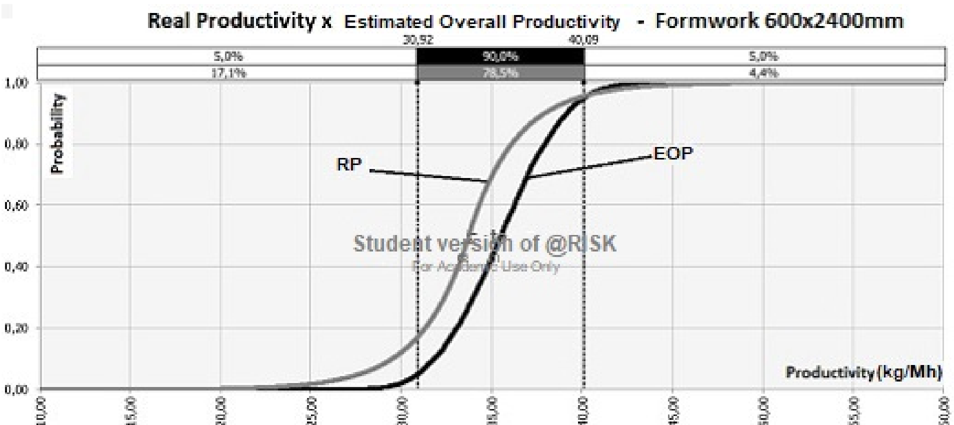
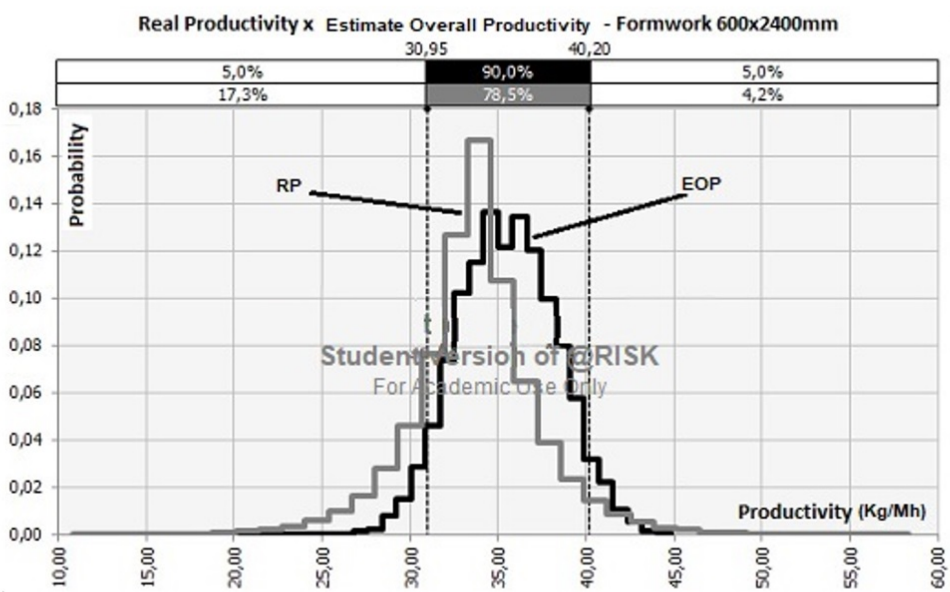


Figure 11 Comparison between probability density function of EOP and RP of aluminium formworks production



4.3 Comparison between EOP and RP

Figures 10, 11, 12 and 13 show the overlap of the curves of CDF and probability density function, for the production of two products, obtained through Monte Carlo simulation from functions: 'EOP' and 'RP'. Likewise, Tables 8 and 9 present the main statistics of functions resulting from the simulation.

Table 8 Comparison between the main statistics of EOP function and RP function of aluminium formworks

Productivity	*Mean (kg/Mh)*	*Mode (kg/Mh)*	*Standard deviation*	*Coefficient of variation (CV)*
EOP	35.51	35.30	2.80	0.08
PR	33.72	33.75	3.70	0.11

Figure 12 Comparison between CDF of EOP and RP of aluminium formworks production – inner corner

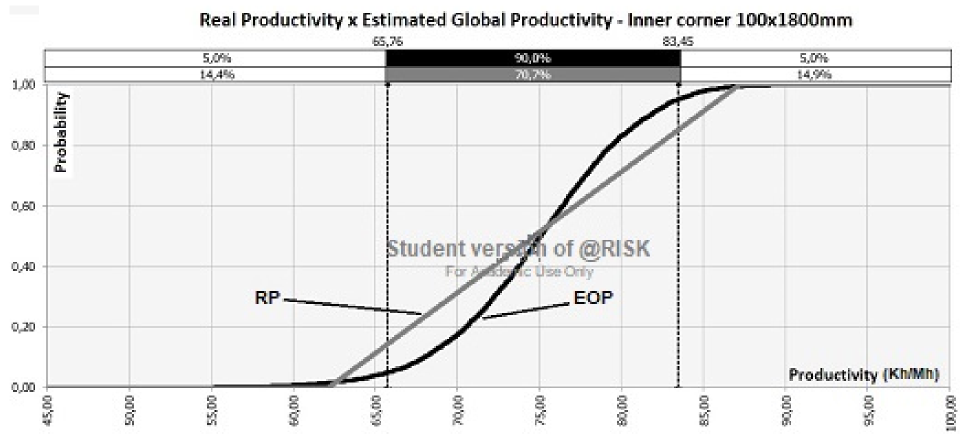
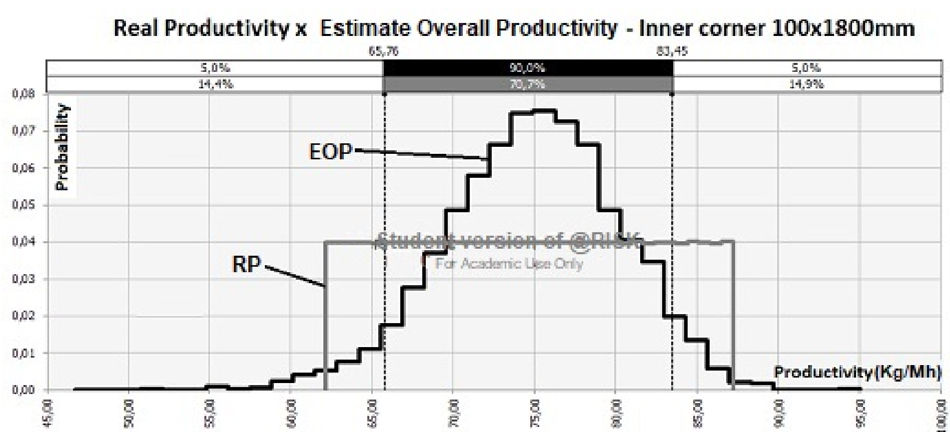


Figure 13 Comparison between PDF of EOP and RP of aluminium formworks production – inner corner

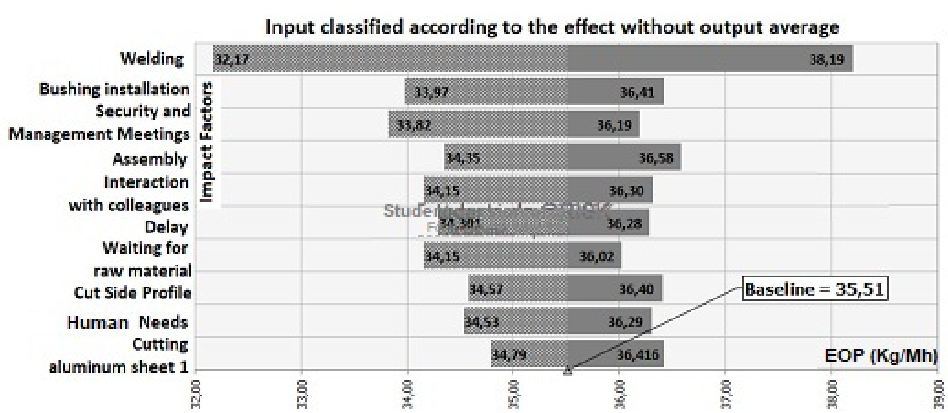


Observing Figures 10, 11, 12 and 13, it is possible to infer that a good adhesion was achieved between 'EOP' and 'RP', indicating that the proposed model to estimate productivity, composed by the functions of productivity of process and idleness, was successful. The results of Tables 8 and 9 show that the differences between the mean and the mode of the two functions are reduced, reinforcing the good adhesion between them. References that allows a comparison with the obtained results for this type of product were not found in the literature. However, Tabim (2013) developed a similar methodology for estimating productivity in pipeline welding, which also presented satisfactory results. On the other hand, the values of coefficient of variation for the two functions indicate that the variability of them is low, which was not expected, since the incorporation of idleness in the EOP function tends to increase them. These results present an opposite trend to the results obtained in the Tabim (2013) and Gióia (2015) studies, where the impact of idleness over productivity is higher. It is worth mentioning that the works developed by these authors were carried out in construction sites, where the means of detected idleness are higher than those recorded in this article, achieving values greater than 0.40. Tables 5 and 6 show that differences between coefficients of variation of 'RP' and 'EOP' functions, for both products, are close. Although, coefficient of variation for 'RP' function, for the two products, are slightly higher. These results can be explained by the fact that, in the collected data that determined the EOP, a trained researcher and a controlled procedure were used, which did not occur in the case of 'RP'. The collection of data of 'RP' was performed by production supervisors without training and a controlled procedure was also not used.

Table 9 Comparison between the main statistics of EOP function and RP function of aluminium formworks – inner corner

Productivity	*Mean (kg/Mh)*	*Mode (kg/Mh)*	*Standard deviation*	*Coefficient of variation (CV)*
EOP	74.89	74.78	5.42	0.07
PR	74.68	77.30	7.22	0.10

Figure 14 Impact factors on the mean of EOP function in the production of aluminium formworks



Figures 14 shows the result of the sensitivity analysis of the 'EOP' function of aluminium formwork production, through the tornado diagram. In the graph, it is observed that the activities of 'welding', 'installation of bushings' and 'safety and management meetings' are, in this order, factors of greatest impact on the increase or reduction of the mean of 'EOP'. It stands out that among these three variables, the 'welding' and 'installation of bushings' activities make up 'PP' function. The 'safety and management meetings' variable is one of the components of 'IF'.

Figure 15 Impact factors on EOP in the production of aluminium formworks – inner corner

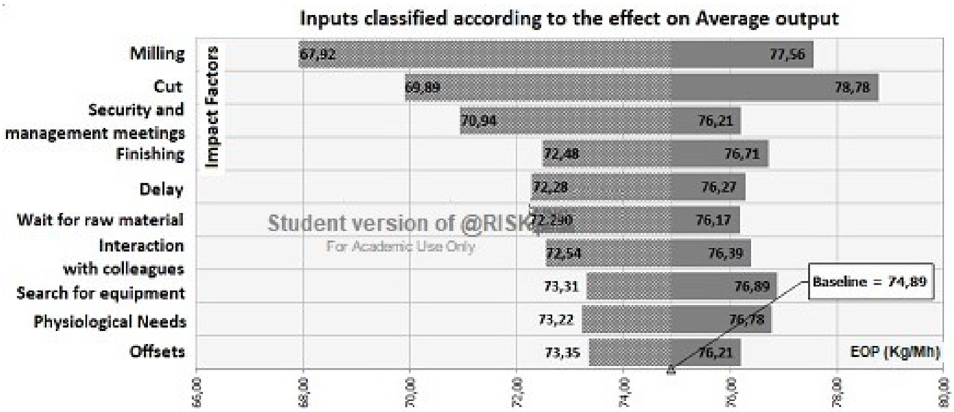


Figure 15 shows the result of the sensitivity analysis of the 'EOP' function of the production of aluminium formwork – inner corner. The graph shows that the activities of 'milling', 'cutting' and 'safety and management meetings' are, in this order, the factors that have the greatest impact on the increase or reduction of the 'EOP' mean. Among these three variables, the 'milling' and 'cutting' activities make up the function 'PP'. The variable 'safety and management meetings' is one of the components of 'IF'.

The sensitivity analysis results are similar to 'EOP' function behaviour for products production. It is observed that, the most significant impact factors over the function of 'EOP' correspond to the activities that make up the 'PP' function. This behaviour is the opposite of the conclusions of Tabim (2013) and Gióia (2015), where the factors with the greatest impact on overall productivity are those that make up the 'IF'. However, as previously highlighted, these works were developed on construction sites, where idleness presents higher values, while in this article it was carried out in a factory.

As pointed out, previously, for the cases of 'PP' and 'IF', the results of the sensitivity analysis, via tornado diagram, presented in Figures 14 and 15, allow that the production management actions can be focused on variables with greatest impact on productivity.

5 Conclusions and future work

The results showed that the proposed model presented good results for estimating productivity for the two studied products and has potential to achieve success in other production processes. The model composed by PP and IFs allows, through sensitivity analysis, to assist production managers directing their actions to improve the productive process and reducing idleness. On the other hand, the implementation of the model does not require a significant amount of resources, and the main investment for its operationalisation should be aimed to organise production quantitative data, to consume Mh and to train a team to operate it. It should underline that in the development of the model, Palisade's @Risk 7.6.1 software was used as a support tool, which substantially facilitates the use of the model. There are other softwares available in the market, which have the same features with similar efficiency. These software are not free, being a negative aspect of the model. It is possible to use the Monte Carlo method with assistance of a free software, such as 'R', however, it is a much more laborious process and with a higher degree of difficulty.

The sensitivity analysis results have showed that the factors of greatest impact over overall productivity of the products studied in this article, are related to the activities which composed the production process. These results present an opposite trend to other papers found in literature, which concentrate on construction sites, where the events that generate idleness, are the ones with the greatest impact. Nevertheless, it is important to point out, that in this article, the productivity data were collected in a factory.

Evaluating the results of this research and the references found in literature review, it was realised that there are future works which may contribute to fill the gap in this issue knowledge, as the development of models for estimating productivity, using the Monte Carlo method, based on data collection through working group techniques, such as: nominal group technique, brainstorming and Delphi technique. Another possibility is carrying out studies focusing on models to estimate the 'baseline productivity', using Monte Carlo method, as well. 'Baseline productivity' corresponds to the best work conditions which is possible to occur in a work environment.

References

Abellana, D.P. (2020) 'An interpretative structural modelling approach to analysing root causes of defective jobs: a case study in an automobile service industry', *International Journal of Productivity and Quality Management*, Vol. 31, No. 1, pp.1–27.

Adrian, J.J. (2004) *Construction Productivity: Measurement and Improvement*, Stipes Publishing Llc., Champagne, IL.

Agarwal, R. and Mehrotra, A. (2020) 'Extracting performance improvement factors using DEA for a robust Indian retail industry', *International Journal of Productivity and Quality Management*, Vol. 30, No. 1, pp.107–125.

Associação Brasileira de Normas Técnicas (ABNT) (2012) *NBR 16055: Parede de Concreto Moldada no Local para a Construção de Edificações – Requisitos e Procedimentos*, Rio de Janeiro [online] https://www.abntcatalogo.com.br/norma.aspx?ID=090554 (accessed 10 December 2020).

Barreto, L.N. (2017) *Estimativa da Produtividade na Fabricação de Tubulações Industriais com Aplicação da Simulação de Monte Carlo*, Unpublished Mestrado thesis, Universidade Federal Fluminense: Mestrado Profissional em Montagem Industrial, Niterói, Rio de Janeiro.

Berlak, J., Hafner, S. and Kuppelwieser, V.G. (2021) 'Digitalization's impacts on productivity: a model-based approach and evaluation in Germany's building construction industry', *Production Planning & Control*, Vol. 32, No. 4, pp.335–345.

Bierman, M., Marnewick, A. and Pretorius, J.H.C. (2016) 'Productivity management in the South African civil construction industry – factors affecting construction productivity', *Journal of the South African Institution of Civil Engineering*, Vol. 58, No. 3, pp.37–44.

Construction Industry Institute (CII) (2006) *Workforce View of Construction Labor Productivity*, RR215-11, Austin, Texas.

Da Silva, F.P., Krueger, J.A. and Xavier, A.A.P. (2010) 'Aplicação do método owas no transporte e manuseio para construção de casas in loco: um estudo de caso', in *ENEGEP 2010: XXX Encontro Nacional de Engenharia de Produção*, pp.1–14.

Durdyev, S. and Ismail, S. (2016) 'On-site construction productivity in Malaysian infrastructure projects', *Structural Survey*, Vol. 34, Nos. 4/5, pp.446–462.

Durdyev, S., Ismail, S. and Kandymov, N. (2018) 'Structural equation model of the factors affecting construction labor productivity', *Journal of Construction Engineering and Management*, Vol. 144, No. 4, p.4018007.

El-Gohary, K.M. and Aziz, R.F. (2014) 'Factors influencing construction labor productivity in Egypt', *Journal of Management in Engineering*, Vol. 30, No. 1, pp.1–9.

Fayek, A.R. (2020) 'Fuzzy logic and fuzzy hybrid techniques for construction engineering and management', *Journal of Construction Engineering and Management*, Vol. 146, No. 7, p.4020064.

Ferreira, M.L.R. et al. (2009) *Relatório do Projeto de Pesquisa: Mapeamento do Estado da Arte da Tecnologia de Construção e Montagem*, Programa de Mobilização Nacional da Indústria do petróleo e Gás Natural (PROMINP), Niterói, Rio de Janeiro, Brazil.

Ferreira, M.L.R. et al. (2010) *Relatório do Projeto de Pesquisa: Métricas de Desempenho da Indústria*, Programa de Mobilização Nacional da Indústria do Petróleo e Gás Natural (PROMINP), Niterói, Rio de Janeiro, Brazil.

Fini, A.F.A., Maghrebi, M., Forsythe, P.J. and Waller, T.S. (2021) 'Using existing site surveillance cameras to automatically measure the installation speed in prefabricated timber construction', *Engineering, Construction and Architectural Management* [online] https://www.emerald.com/insight/content/doi/10.1108/ECAM-04-2020-0281/full/html (accessed 30 April 2021).

Fu, J., Tian, H., Song, L., Li, M., Bai, S. and Ren, Q. (2021) 'Productivity estimation of cutter suction dredger operation through data mining and learning from real-time big data', *Engineering, Construction and Architectural Management* [online] https://www.emerald.com/insight/content/doi/10.1108/ECAM-05-2020-0357/full/html (accessed 30 April 2021).

Gióia, A.L. (2015) *Fatores de Impacto na Soldagem de Tubulações Industriais*, Unpublished Mestrado thesis, Universidade Federal Fluminense: Mestrado Profissional em Montagem Industrial, Niterói, Rio de Janeiro.

Golnaraghi, S., Moselhi, O., Alkass, S. and Zangenehmadar, Z. (2020) 'Modelling construction labour productivity using evolutionary polynomial regression', *International Journal of Productivity and Quality Management*, Vol. 31, No. 2, pp.207–226.

Gurmu, A.T. and Ongkowijoyo, C.S. (2020) 'Stochastic-based model for setting formwork-productivity baseline', *Journal of Construction Engineering and Management*, Vol. 146, No. 9, p.4020099.

Hasan, A., Baroudi, B., Elmualim, A. and Rameezdeen, R. (2018) 'Factors affecting construction productivity: a 30 year systematic review', *Engineering, Construction and Architectural Management*, Vol. 25, No. 7, pp.916–937.

Hickson, G.B. and Ellis, A.L. (2014) 'Factors affecting construction labour productivity in Trinidad and Tobago', *The Journal of the Association of Professional Engineers of Trinidad and Tobago*, Vol. 42, No. 1, pp.4–11.

Ibbs, W. and Sun, X. (2017) 'Weather's effect on construction labor productivity', *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, Vol. 9, No. 2, p.4517002.

Li, X., Li, H., Skitmore, M. and Wang, F. (2021) 'Understanding the influence of safety climate and productivity pressure on non-helmet use behavior at construction sites: a case study', *Engineering, Construction and Architectural Management* [online] https://www.emerald.com/insight/content/doi/10.1108/ECAM-08-2020-0626/full/html (accessed 30 April 2021).

Lobato, M.M. (2015) *Utilização de Misturas com Argônio e CO2 na Soldagem de Arames Tubulares em aço Carbono ASTM A36*, Unpublished Mestrado thesis, Universidade Federal Fluminense: Mestrado Profissional em Montagem Industrial, Niterói, Rio de Janeiro.

Mani, N., Kisi, K.P., Rojas, E.M. and Foster, E.T. (2017) 'Estimating construction labor productivity frontier: pilot study', *Journal of Construction Engineering and Management*, Vol. 143, No. 10, p.4017077.

Martins, J.L.F. (2011) *Aplicação de Simulação com Métodos de Monte Carlo e Hipercubo Latino na Estimativa de Produtividade no Processo de Soldagem por Eletrodo Revestido*, Unpublished PhD thesis, Universidade Federal Fluminense, Niterói, Rio de Janeiro.

Martins, J.L.F. and Ferreira, M.L.R. (2013) 'Aplicabilidade de simulação utilizando os métodos de Monte Carlo e Hipercubo Latino na estimativa de produtividade do processo de soldagem TIG', in *COBEF: 7th Congresso Brasileiro de Engenharia de Fabricação* [online] http://www.swge.inf.br/siteCOBEF2013/anais/PDFS/COBEF2013-0293.PDF (accessed 30 April 2021).

Motlagh, M.A., Valmohammadi, C. and Modiri, M. (2020) 'Developing a qualitative model of productivity for service companies using fuzzy analytic hierarchy process: a case study', *International Journal of Productivity and Quality Management*, Vol. 29, No. 1, pp.126–147.

Nasirzadeh, F., Kabir, H.M.D., Akbari, M., Khosravi, A., Nahavandi, S. and Carmichael, D.G. (2020) 'ANN-based prediction intervals to forecast labour productivity', *Engineering, Construction and Architectural Management*, Vol. 27, No. 9, pp.2335–2351.

Neto, A.A., Lima, R.M., Afonso, P.S.L.P and Da Silva, N.T. (2018) 'Análise da adoção de práticas lean em empresas brasileiras: um estudo exploratório', *Sistemas & Gestão*, Vol. 13, No. 2, pp.196–208.

Ney, D.C. (2016) *Avaliação da Metodologia Eletrônica para Monitoramento do Desempenho de Soldadores na Fabricação de Tubulações*, Unpublished Mestrado thesis, Universidade Federal Fluminense: Mestrado Profissional em Montagem Industrial, Niterói, Rio de Janeiro.

Ney, D.C. and Ferreira, M.L.R. (2018) 'Agile methodology to performance measure and identification of impact factors in the labour productivity of industrial workers', *U. Porto Journal of Engineering*, Vol. 4, No. 2, pp.49–64.

Rad, K.G. and Kim, S-Y. (2018) 'Factors affecting construction labor productivity: Iran case study', *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, Vol. 42, No. 2, pp.165–180.

Raoufi, M. and Fayek, A.R. (2020) 'Fuzzy Monte Carlo agent-based simulation of construction crew performance', *Journal of Construction Engineering and Management*, Vol. 146, No. 5, p.4020041.

Sasseron, R.H. and Nakabashi, L. (2018) 'Determinantes da produtividade: análise do impacto do índice GCI e seus componentes sobre a PTF', *Revista Brasileira de Economia*, Vol. 72, No. 2, pp.249–274.

Shehata, M. and El-Gohary, K. (2011) 'Towards improving construction labor productivity and projects' performance', *Alexandria Engineering Journal*, Vol. 50, No. 4, pp.321–330.

Soares, I.O., de Carvalho, A.W.B., Filho, G.B.R. and Pinto, N.M.A. (2013) 'Interesses especulativos, atuação do Estado e direito à cidade: o caso do programa 'Minha Casa Minha Vida' em Uberaba (MG)', *URBE, Revista Brasileira de Gestão Urbana*, Vol. 5, No. 1, pp.119–131.

Tabim, P.M. (2013) *Estimativa de Produtividade na Soldagem de Dutos Terrestres com Aplicação da Simulação de Monte Carlo*, Unpublished Mestrado thesis, Universidade Federal Fluminense: Mestrado Profissional em Montagem Industrial, Niterói, Rio de Janeiro.

Tabim, P.M., Ferreira, M.L.R., Morano, C.A.R. and Martins, J.L.F. (2016) 'Avaliação da produtividade da soldagem de dutos terrestres via simulação de Monte Carlo e análise de sensibilidade', *Revista Militar de Ciência e Tecnologia*, Vol. 33, No. 2, pp.19–27.

Vaux, J.S. and Kirk, W.M. (2018) 'Relationship conflict in construction management: performance and productivity problem', *Journal of Construction Engineering and Management*, Vol. 144, No. 6, p.4018032.

Vogl, B. and Abdel-Wahab, M. (2015) 'Measuring the construction industry's productivity performance: critique of international productivity comparisons at industry level', *Journal of Construction Engineering and Management*, Vol. 141, No. 4, p.4014085.

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.