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COMMISSIONING OF CONTROL SYSTEMS WITH DISCRETE EVENT SIMULATION IN URURAU SOFTWARE

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Abstract. *This work presents a hybrid environment to be applied in the commissioning of control systems. The environment comprises a software used to construct discrete event simulation models and a pneumatic bench of tests. The simulation software is the Free and Open-Source Software Ururau, which is the first Brazilian software designed to construct discrete simulation models. A simulation model of an industrial plant, which was integrated to a Programmable Logic Controller (PLC) of the test bench, was constructed to demonstrate the use of the environment. The model simulated a manufacture system with processes of turning, inspection, drilling and rectification. The controller worked on the inspection performed automatically on the test bench. The preliminary results showed the feasibility of applying the Ururau software integrated to digital controllers for tests in automated industrial processes*

Keywords: *Ururau, OPC, PLC, Pneumatic bench*

1. INTRODUCTION

This work presents a mechanism to integrate a discrete event simulation model with control system by means of Programmable Logic Controller (PLC). The possibility of integrating the discrete simulation models with control systems was raised for more than a decade by Dougall (1998) and Banks (2000). Currently, there are many commercial softwares that offer some type of mechanism for communication among the simulation models and the controllers, such as Arena, Automod, among others. However, the only Brazilian software that can be used in the construction of discrete event simulation models is the Ururau, which is described in detail in (Peixoto et al., 2013). Ururau is a Free and Open Source Software (FOSS) and multiplatform as it is developed in Java language.

There are other softwares that are traditionally used for simulation of control loops in industrial processes by mathematical modeling such as the Matlab/Simulink®. There is the possibility, in this work, to use the environment of discrete event simulation and, consequently, the insertion of actions with stochastic data associated. This way, among other things, the spontaneous relation of the operator with the process can be analyzed and represented; in other words, the randomness of the action/reaction of the operator can be represented, as in the case, for example, of the need of an intervention in the system from a manual inspection.

Therefore, the aim of this work was to describe a hybrid environment that can be applied in the commissioning of digital control systems for tests in automated industrial processes. A simulation model of an industrial facility was integrated to a PLC in a test bench of pneumatic drives. The model simulated a hypothetical production system typically used in industrial processes. The controller operated in the inspection automatically performed in the bench.

2. EXPERIMENTAL PROCEDURE

2.1 System for testing

The system, objective of this work, refers to a typical environment of industrial production line. The model handles a system of production line of a hypothetical auto parts plant. The system is composed by a Productive Cell with 4 Work Stations described in Figure 1.

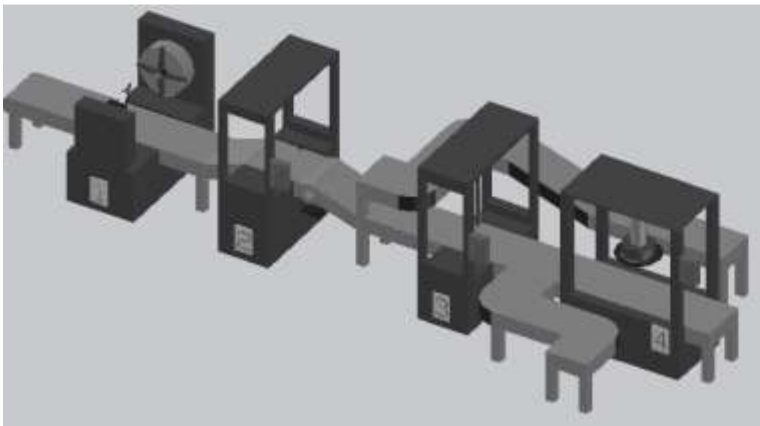


Figure 1. Hypothetical system to represent the system: (1) Turning, (2) Inspection, (3) Drilling e (4) Rectification.

The first work station is a Turning. This Turning has a process time that follows a normal function with average of 3 minutes and standard deviation of 1 minute. Right after the Turning, there is an Inspection station that is carried out by an operator. The time of the Inspection process corresponds to a normal of average of 2 minutes and standard deviation of 1 minute, and 10% of the parts are discarded because of quality problems. There is a manual drilling, after the Inspection station, which needs an operator in order to operate, with time process that follows a triangular of (2, 3, 4.5) minutes. The parts that leave the Drilling can only be taken to the Rectification, with operation time that follows a normal with average of 3 minutes and standard deviation of 1 minute, if its queue of parts in standby is less than 6. In case the queue is greater than or equal to 6, the parts are deviated to another line in order not to interrupt the production.

The parts containing imperfections form batches of 5 parts and are eliminated from the line by a forklift with process time of 2 minutes and standard deviation of 1 minute.

The arrival of the parts at the Production Cell occurs according to an exponential function of average of 3.5 minutes in the work station of the Turning.

2.2 Simulation model

According to Medina and Chwif (2013), a model is a simplified representation of the reality of the different interactions among the parts of a system. “A model is, therefore, an abstraction of reality that is close to the real behavior of the system but frequently simpler than the real system”. When thinking about a system, it is usually associated to a real one that physically exists. A hypothetical system can also be simulated even if its validation is more difficult. The computational simulation is an imitation of the operation of a process by means of the functioning of other by using the computer. It is a test, an experience, an essay. It should be elaborated, previously, a conceptual model to facilitate the construction of the computational model.

Thus, as Rangel et al. (2013) present, before constructing the simulation environment for tests in control systems, it is necessary a description of the model to be tested. This description should be done by the conceptual model, where the information about all the process are graphically exposed to better understand all that will be executed in the simulation. The IDEF-SIM language, described in Montevechi et al., 2010, was applied in order to construct the conceptual model.

The conceptual model was elaborated with the support of the DIA software. This software comes from a project of scientific initiation and aims at helping the implementation of conceptual models in IDEF-SIM. Both IDEF-SIM language and DIA software were developed by the Federal University of Itajubá (UNIFEI) and may be freely downloaded at (http://www.unifei.edu.br/projeto-dia).

Figure 2 presents the conceptual model. Module (E1) represents the arrival of entities (parts) in the system. The parts are addressed to the first point of the line, which is the turning process (F1) in the mechanical Turning (R1). Then, the parts go to the point 2 of the production line, that is, the inspection process (F2), carried out by an Inspector (R2). He analyses the part and decides if it is able to go to the point 3 of the line, which is the drilling process (F3) executed by a Drilling (R3). The part is discarded and collected by a Stacking (R5) in the process of stacking (F5) if any imperfection in it is identified. After the drilling process (F3), the parts go to the process of rectification (F4), carried out in the Rectification (R4). If there are more than 6 parts in the queue to the Rectification, the parts will be deviated to another line.

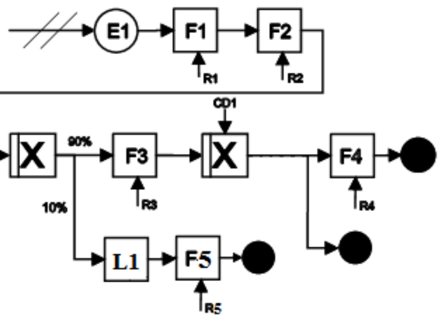


Figure 2. Conceptual model implemented in the DIA software

Table 1 presents the information about the data of each process existent in the simulation model.

Table 1. Description of the functions presented in the simulated model.

Description	Parameter
Entity: Parts	Function: EXPO (3.5) min; 1 at a time; maximum infinite; first arrival
Process: Turning	Function: NORM (3,1) min; quantity: 1
Process: Inspection	Function: NORM (2,1) min; quantity: 1
Process: Drilling	Function: TRIA (2, 3, 4.5) min; quantity: 1
Process: Rectification	Function: NORM (3,1) min; quantity: 1
Process: Stacking	Function: NORM (2,1) min; quantity: 1
Resource: Turning machine	Quantity: 1
Resource: Inspector	Quantity: 1
Resource: Drilling machine	Quantity: 1
Resource: Rectification machine	Quantity: 1
Resource: Stacking machine	Quantity: 1
CD1: Decides the route of the part in function of the size of the queue.	If F4< 6 then the part goes to Rectification

The model was executed in time of 12h, characterizing the model as a terminal system. The simulations were initialized only after the model has been fully verified and validated. (SARGENT, 2011)

2.3 Integration of the simulation model and control system

A real environment can be represented by a simulation model, which allows being controlled the same way as a real system. This is an important tool as it permits to identify the best conditions of functioning of a system, reducing costs and risks. The analysis of control systems can aid in the decision making in production lines as, for example, when entities gather in a queue, creating a bottleneck in a specific process. Thus, the arrangement should be changed so that it is eliminated (INUKAY, 2007 e WYSK, 1995).

To perform the integration of the simulation model with the PLC, the model described in the software Ururau was implemented. The construction of the models in the Ururau environment is simple as it is not necessary to type any line of command. Just when you need to select from the toolbar of the module desired function and drag it to the desktop software.

Figure 3 shows the simulation model in the Ururau environment, and the window where the OPC communication has to be activated in the software. When the communication is activated, a list of variables that can be used in the simulation model appears for the user. These variables were defined in the OPC server.

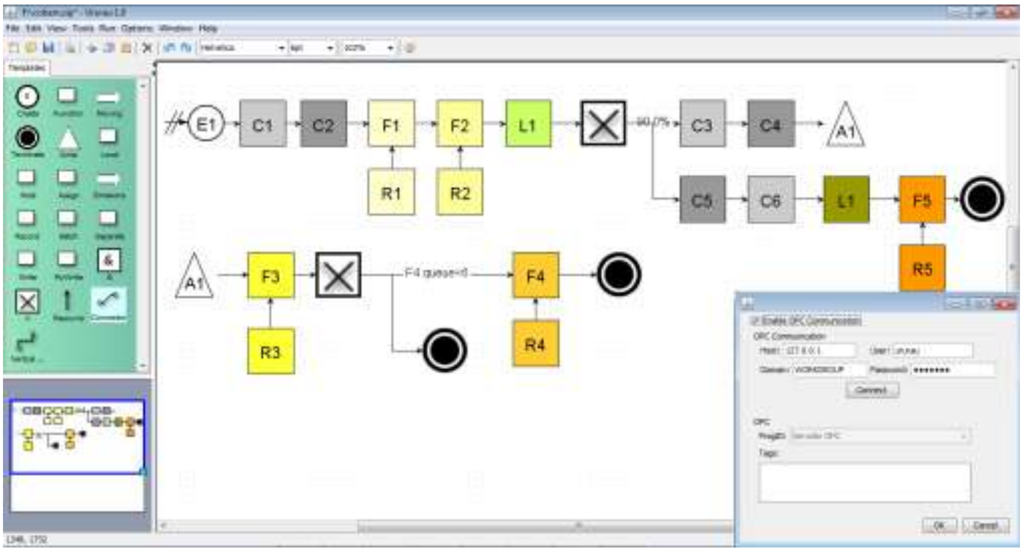


Figure 3. Computational Model in Ururau environment

After the construction of the simulation model, the next step is the creation of the control logic responsible by the integration of the components.

A form of control of a system is the use of a Programmable Logic Controller (PLC). A PLC is a digital device that allows controlling a system due to a programmable memory that receives instructions to be transferred to the machines responsible for the industrial process, so that they execute the process. Nowadays, the PLC, due to the evolution, is able to execute sequencing, timer, counting, energization/power down) and data manipulation among other functions. The PLCs can be programmed by means of computers, are suitable for the industrial environments and have simple language. (GOEKING, 2010)

A PLC is basically composed by input modules, output modules and communication modules. The input module (or contact) can read the value of a Boolean variable (0 or 1), and the output (coil) can write the value of a Boolean variable. Table 2 shows the description of the elements used in the programming of the control logic.

Table 2. Description of the elements presented in the control logic

Symbol	**Description**
--] [--	Contact NO (Normally open)
--]\[--	Contact NC (Normally closed)
--( )--	Output (On)

Figure 4 details the programming interface of the PLC from Siemens, model SIMATIC S7-1200, with control logic in Ladder. Two contacts were used in the control logic; the first one is a contact NO, which reads the value of the variable when the actuator is receded. The second contact is NC, which reads the value of the input variable, making that the actuator changes its position from receded to activated after receiving a, output signal. The actuator advances and recedes consecutive times while the simulation model integrated to the control system is running.

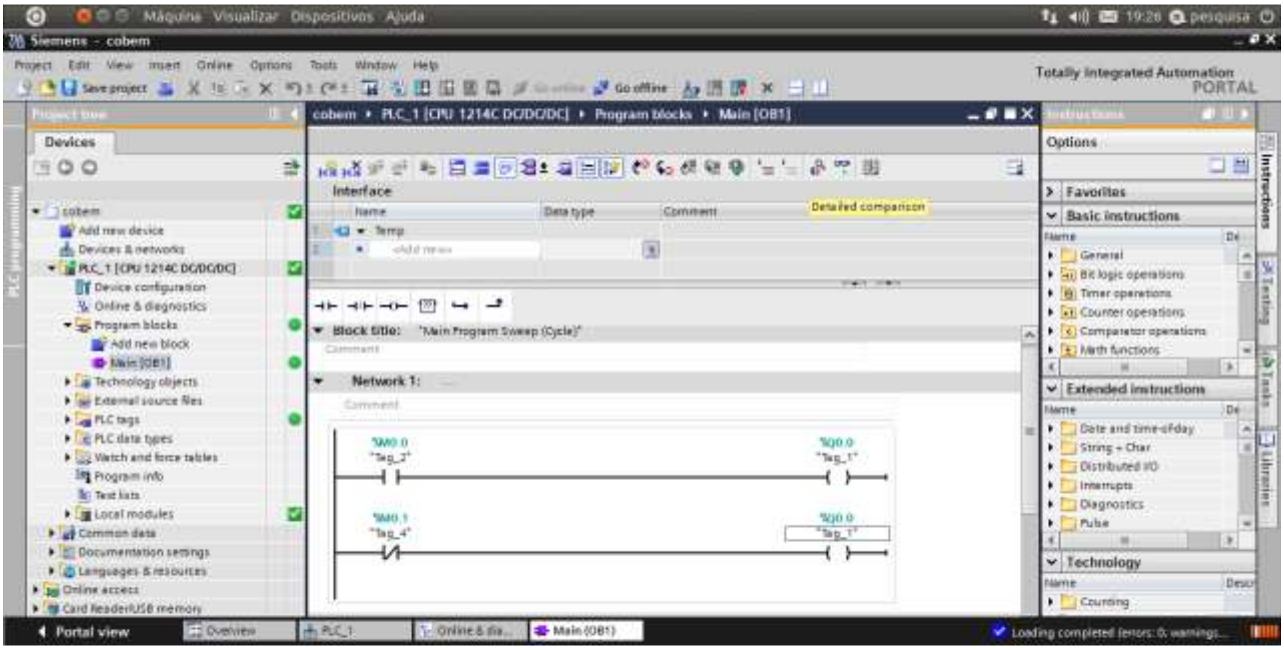


Figure 4. Programming in Ladder

To have the communication and the integration between the simulation model and the control system, the following applications are used.:

- Simulation environment Ururau;
- PLC Siemens;
- KEPServer.

As it is described by Atual (2013), in order to have communication between the simulation model and the PLC, it is necessary the use of an OPC interface (Object Linking and Embedding for Process Control), that consists of the linking to the control of a process. That standardized interface of communication was created to try to minimize the problems related to the inconsistency of the drivers and industrial equipment from different manufacturers.

It is necessary to create a connection to access the data in the OPC server so that the communication among the components occurs.

This way, the model variables can be connected to the controller tags. These tags are Inputs (I) and Outputs (O) contained in the PLC (CHWIF, 2002 e SMITH, 2008). In the OPC server, Boolean variables, C.D.U.forward and C.D.U.backward were defined in a way that the first commands the advance of the actuator, which moves a ramp directing the defective parts to another conveyor, and the second one makes that the ramp returns to its initial state.

This process occurs after the inspector's decision about the quality of the part. When the communication is activated in the Ururau software, a list of all the variables created in the OPC server are listed, as already mentioned. Figure 5 presents the KEPServer work area.

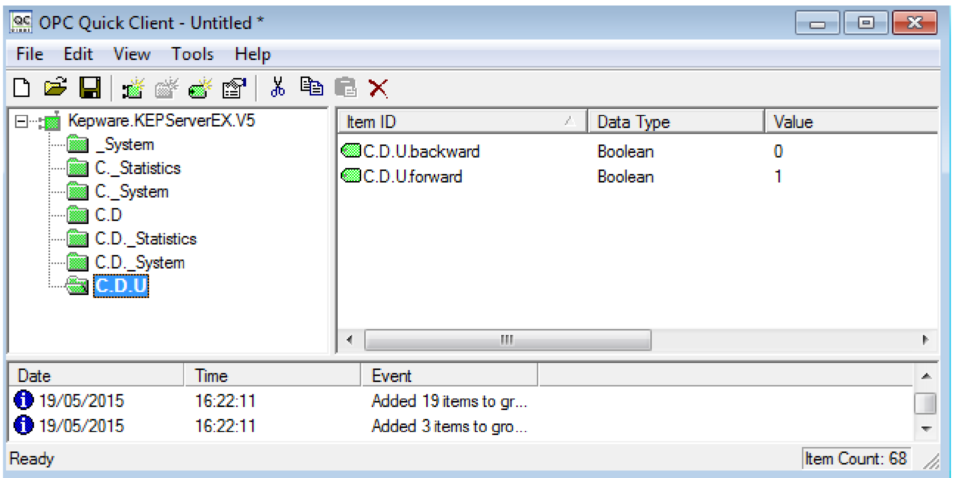


Figure 5. KEPServer work área

A pneumatic bench of tests was used to better visualize the information exchange among the components.

Figure 6 shows the pneumatic bench having a directional solenoid valve (1) that directs the flow of compressed air supplied by a compressor to which the actuator will move from indented (3) driven to (4). All actions are controlled by the PLC present on the counter (2).

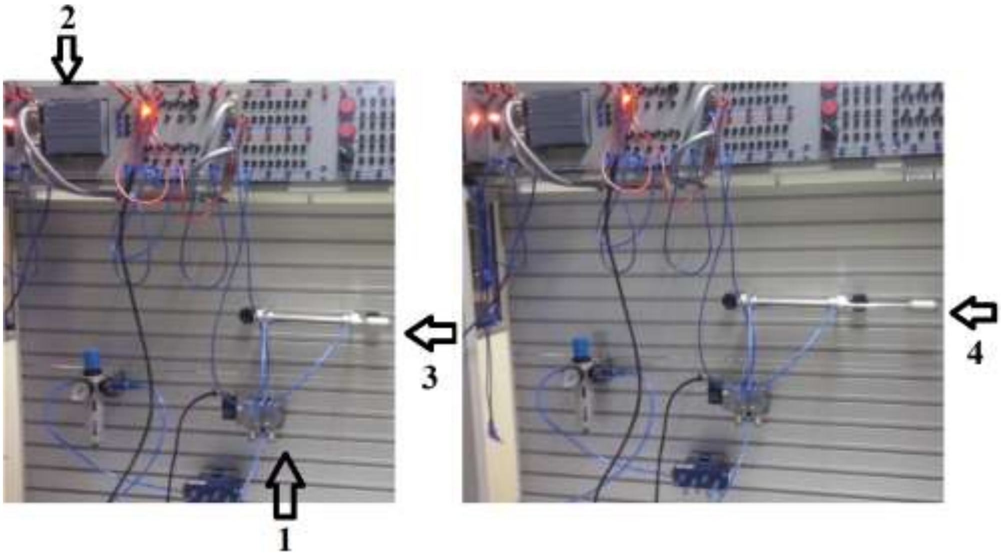


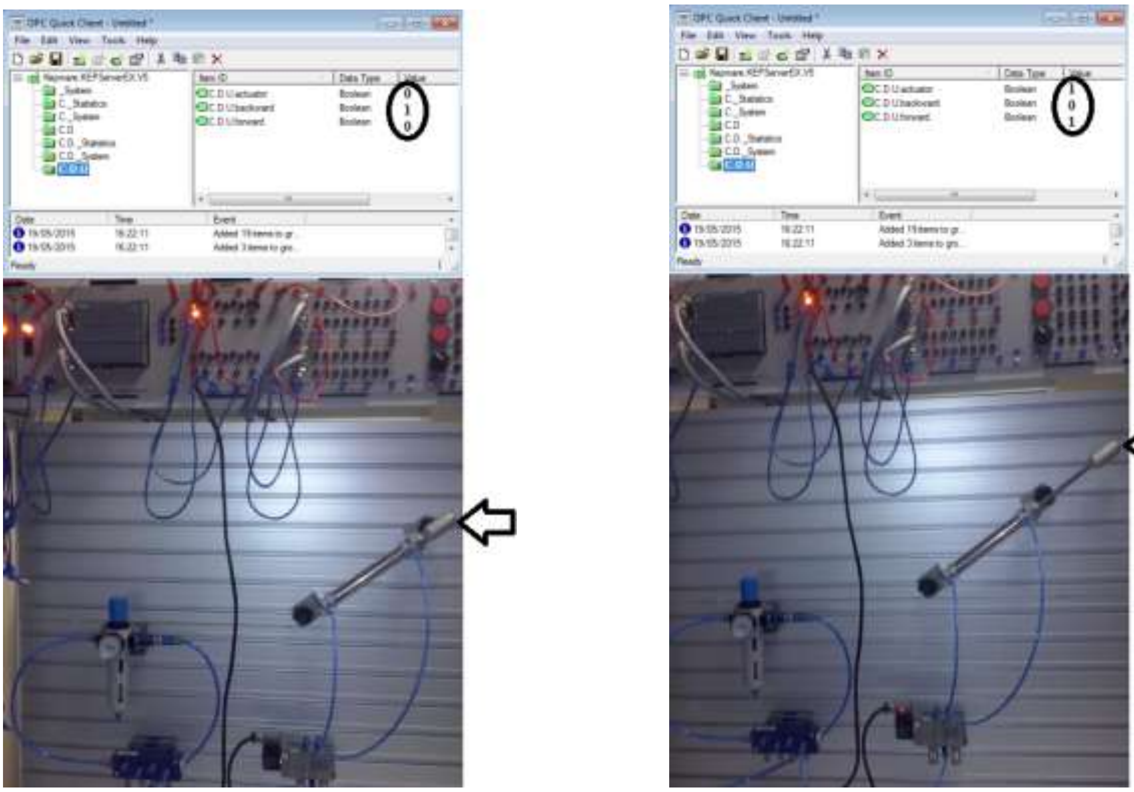
Figure 6. Pneumatic bench of tests with a solenoid valve (1), a PLC (2), an actuator of double action receded (3) and actuated (4). Source: The author himself

3. TESTS OF THE SYSTEM

When performing the tests in the pneumatic bench, it can be visualized the movement of an actuator of double action, which is controlled by a PLC that sends signal to advance or recede. Bringing it for application, this PLC controls the movement of the ramp in the production line, which takes the parts to two destinations, two conveyors: the part goes to other processes or is discarded. If the control of this ramp was manual, every time the part was reproved in the process of inspection, the operator (inspector) would have to activate a button so that the operation could happen. However, using the automatic control, this process turns to be simpler. Then, the operator has only to direct his concern to the inspection process.

This control system could be installed in other equipment of the line, like the bit of the drilling machine, advancing toward the part to be drilled or the lathe castle, advancing up to the surface to be turned. But, for these purposes, the application chosen achieved the aim suggested: demonstrate the integration between the simulation software and the PLC. In fact, the use of the bench is important to make visible, leaving the virtual, what this system can cause being taken to a real application, because it is possible to analyze the work of the actuator verifying only the screen of KEPServer as it is presented in the upper part of Figure 7.

Thus, Figure 7 shows the state of the test system in its two stages, activated and receded. The variable (C.D.U.forward), when inside the KEPServer, has value 1, the actuator receives the order to advance. When the variable (C.D.U.backward) receives the value 1, the actuator moves back. The variable (C.D.U.actuator) was inserted in the OPC communicator to become visible the present state of the actuator. When this variable receives value 1, the actuator is activated and, when this variable receives value 0, the actuator is receded.



(a) (b)

Figure 7. Work station KEPServer and pneumatic bench with: (a) **actuator receded and (b) actuator activated.**

4. FINAL REMARKS

The results presented during the tests performed with the hybrid environment, formed by the simulation model and pneumatic bench, showed the feasibility of the application of the software Ururau integrated with digital controllers for tests in automated industrial processes. The tests with the mechanism exposed in this work for integration of simulation models with control systems showed themselves as efficient and attended the objectives proposed.

The results allowed raising an issue about the possibility to extend the use of the pneumatic didactic bench with the simulation models connected to the controllers existed in the bench. That is, once integrated the simulation model with the bench of the laboratory, it was obtained an environment with greater number of possibilities of didactic examples, besides permitting the visualization of the control system integrated with a simulated industrial plant

It is expected that, through the present work, the possibility of use of tests and training in control systems using discrete event simulation models with the software Ururau is being opened. It is also highlighted that the creation of the Ururau has as main objective to contribute to facilitate the diffusion, use and understanding of simulation in Brazil from its practical application to the internal conception of its computational structure and source code.

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5. REFERENCES

DOUGALL, D. J. *Applications and benefits of real-Time I/O simulation for PLC and PC control systems*. ISA Transactions. Vol. 36. Nº 4: p. 305-311, 1998.

BANKS, J. *Simulation in the Future. In: Winter Simulation Conference*, Orland, USA. P. 1568 -1576, 2000.

PEIXOTO, T.A. & RANGEL, J.J.A. & MATIAS, I. O & MONTEVECHI, J.A.B. & MIRANDA, R.C. (2013). Ururau – Um Ambiente para Desenvolvimento de Modelos de Simulação a Eventos Discretos. PODes - Revista Eletrônica Pesquisa Operacional para o Desenvolvimento. Vol.5, n.3, p.373-405.

RANGEL, João José de Assis; OLIVEIRA, Gabriel Lima de; PEIXOTO, Túlio Almeida; MATIAS, Ítalo de

Oliveira; SHIMODA, Eduardo; CARDOSO, Leonardo das Dores. *Simulation model in a free and open-source software for carbon monoxide emissions analysis***.** In: Proceedings of the WINTER SIMULATION CONFERENCE, 45., 2013, Washington. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, 2013. p. 1905 - 1916. Disponível em: <http://informs-sim.org/wsc13papers/includes/files/167.pdf>. Acesso em: 20 abr. 2015.

MONTEVECHI, José Arnaldo Barra; LEAL, Fabiano PINHO, Alexandre; COSTA, Rafael Florêncio; OLIVEIRA, Mona Liza; SILVA, André Luís. *Conceptual modeling in simulation projects by mean adapted idef: an application in a brazilian tech company***.** In: Proceedings of the WINTER SIMULATION CONFERENCE, 42, 2010, Baltimore. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, 2010. p. 1624 - 1635. Disponível em: <http://www.informs-sim.org/wsc10papers/150.pdf>. Acesso em: 20 abr. 2015.

SARGENT, Robert G.. *Verification and validation of simulation models***.** *In: Proceedings of the* WINTER SIMULATION CONFERENCE, 43. 2011, Arizona. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, 2011. p. 183 - 198. Disponível em: <http://www.informs-sim.org/wsc11papers/016.pdf>. Acesso em: 20 abr. 2015.

MEDINA, Afonso Celso; CHWIF, Leonard**o.** *Modelagem e Simulação de Eventos Discretos***:** Teorias e Aplicações. 3. ed. Rio de Janeiro: Campus Editora, 2013. 312 p.

INUKAY, T.; HIBINO, H.; FUKUDA, Y. *Simulation Environment Synchronizing Real Equipment for Manufacturing Cell - J. Adv. Mec***.** Design, Systems and Manufacturing, Vol.1, Nº 2, pp. 238-249, 2007

GOEKING, Weruska. *Memória da eletricidade: Da máquina a vapor aos softwares de automação. O Setor Elétrico***,** São Paulo, v. 5, n. 52, p.70-77, maio 2010. Disponível em: <http://test.voltimum.com.br/sites/www.voltimum.com.br/files/memoria_maio_10.pdf>. Acesso em: 25 abr. 2015.

ATUAL, Mecatrônica. *O que é OPC?* 2013. Originalmente publicado na revista Mecatrônica Atual nº42. Disponível em: <http://www.mecatronicaatual.com.br/educacao/1298-o-que-opc>. Acesso em: 27 abr. 2015.

CHWIF, L. *Utilizando a Simulação de Eventos Discretos em Projetos de Sistemas Automatizados de Manufatura.* Anais do 10º Congresso e Exposição Internacional de Automação, CONAI, São Paulo, SP, 2002.

SMITH, Jeffery S.; CHO, Younchol. *Offline commissioning of a plc-based control system using arena*. In: Proceedings of the WINTER SIMULATION CONFERENCE, 40. 2008, Miami. Piscataway, New Jersey: Institute of Electrical And Electronics Engineers, 2008. p. 1802 - 1810. Disponível em: <http://www.informs-sim.org/wsc08papers/222.pdf>. Acesso em: 20 abr. 2015.