Simulation of human-machine interaction in an automotive manufacturing cell using Digital Factory (DF)

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Abstract: Digital Factory (DF) is defined as a set of production process development-oriented softwares, involving from the planning through the implementation of such processes. This work presents the application of DF tools in the study of man-machine interaction in a manufacturing process. Therefore, first, a theoretical background on the subject and then a case study of the assembly process in a European automaker in Brazil are developed. Finally, the adherence of the model to the real situation is evaluated. Results and suggestions for a future work are presented and the work is concluded with pertinent considerations.

Keywords: Digital Factory (DF), software, carmaker, automotive manufacturing.

1. Introduction

Product Development Process (PDP) can be defined as a set of activities organized in macro-phases and phases sequentially disposed comprising product concept, development of the product and manufacturing process, production and product distribution in the market. Systems supporting PDP activities use virtual and physical systems. Digital Factory is among the virtual systems (KÜHN, 2006; SILVA, 2013).

The concept Digital Factory (DF) offers an integrated approach to improve the processes of product and manufacturing process engineering. DF can be defined as the generic term for a network that comprises digital models, methods and tools - including 3D simulation and visualization - integrated by a continuous system of data management. Its purpose is to integrally plan, evaluate and continuously improve all main structures, processes and resources of the real factory, together with the product (POLÁŠEK; BUREŠ; ŠIMON, 2015). Its initial focus is on the planning of production and factory design, coordinated with all corporative processes (KÜHN, 2006; VEREIN DEUTSCHER INGENIEURE, 2008).

DF's vision focus on the integration in different levels of methods and tools available to plan and test the product, related manufacturing and operational control of the plant. Thus, it integrates the following PDP stages: product design/development, test and optimization, manufacturing design/development, process optimization, manufacturing process implementation, and planning and control of manufacturing operation (KÜHN, 2006; SILVA, 2013).

This work aims to present the use of DF tools in the production process development, mainly addressing the study of man-machine interaction.

This study is divided in 5 sections. Introduction and structure of the article are in Section 1. Section 2 presents a theoretical background on the subject. A case study is presented in Section 3 and its results analysis is presented in Section 4. In Section 5, suggestions for a future work are identified and presented and the work is concluded with considerations pertinent to the subject.

2. Theoretical background

The theoretical background developed by Bracht, Geckler and Wenzel (2011) and updated by Silva and Kaminski (2015) has been complemented and categorized to evaluate the scientific production on the subject and the current DF applications in production process development. The search was performed mainly in publications between 2001 and 2016. The articles were tabulated and summarized according to their main information. The articles were also classified as part of Product Development Process (PDP) and Digital Factory (DF), according to the application fields: product design/development, process design/development, process implementation, plant operation, DF concept/theory. Search result, summary and classification of theoretical background can be seen in Table 1.

Table 1. FD articles classified and their summaries (updated, complemented and categorized from Bracht, Geckler and Wenzel (2011); Silva and Kaminski (2015)).

Author	Main subject	Classification	Year
Bley and Franke*	Models management Exchange of information Knowledge management	Process design/development	2001
Dombrowiski et al.*	Virtual model of the real plant to be used Mapping of all project resources Computer-aided factory processes	DF concept/theory and Process design/development	2001
Bracht*	Link between product development and production planning	DF concept/theory and Process design/development	2002
Wiedahl*	Computational model	DF concept/theory and Process design/development	2002
Westkämper et al.*	Information model	DF concept/theory	2003
Wenzel et al. *	Digital models connected to the network Methods and tools	DF concept/theory and Process design/development	2003
Maropoulos	Digital enterprise technology (DET)	DF concept/theory and Process design/development	2003
Marczinski*	Computer-aided engineering tools	Process design/development	2006
Verein Deutscher Ingenieure	Guidelines and foundations	DF concept/theory	2008
Kim et al.	Assistant to digital factory	DF concept/theory	2010
Américo and António	Models of factories	Process design/development	2011
Silva, Kaminski and Gruber	Investigation of available DF resources in the analysis of workforce	Process design/development	2014
Büttner	Development and expansion of DF concept towards Industrie 4.0	Plant operation	2014
Silva and Kaminski	Digital factory concepts manufacturing cells design	Process design/development	2015
Krückhans and Meier	Communications between real and virtual DF components in a plant structure	Process design/development and factory operation	2015
Choi, Kim and Noh	Planning, design and application strategy of DF in real industries	DF concept/theory and Process design/development	2015
Husár and Dupláková	Use of DF in logistic planning	Process design/development	2015
Or and Zou	Tools and aplications of DF	DF concept/theory and process implementation	2015
Polásek, Bures and Simon	Comparision between ergonomie softwares	DF concept/theory and Process design/development	2015
Toro, Barandiarana and Posadaa	Implementation of Systems of Intelligence in Industry 4.0	Process design/development and process implementation	2015
Harrison, Vera and Ahmad	Analysis of methods of use of Cyber-Physical Systems	Process design/development	2016
Cherubini et al.	Human-machine cooperation in the manufacturing process	Process design/development	2016

*apud Bracht, Geckler and Wenzel (2011).

3. Case study

Proposed case study is based on a real automotive manufacturing cell of an European automaker branch installed in Brazil. The studied case concerns the assembly cell of the turn signal switch set, where a single worker is responsible for assembling different types, according to the car models manufactured by the automaker. Figure 1 shows the manufacturing cell addressed in the case study.

Table 2 shows a list of components used in the assembly of turn signal switch set, and the corresponding storage position in the manufacturing cell.

Real cell layout, parts distribution, worker's working way and assembly sequence were considered to evaluate man-machine interaction. All these factors allowed to adjust the model to the real case.

Tecnomatix Plant Simulation v.11 (SIEMENS, 2016) was used for model development. This software allows modeling, simulation and validation of discrete systems. Figure 2 shows an abstract model containing the main elements used in the modeling of manufacturing cell.

Detailed model simulates two main parts of the task: path performed by the worker during parts selection and

Table 2. Components of turn signal switch set and storage position.

Storage position	Components
1	Lining
2	Lower Cover
3	Upper Cover
4	Steering Column
5	Switch
6	Box Panel
7	Storage Compartment
8	Lining
9	Mount
10	Fuse
11	Clamp
12	Bolt
13	Assembly station

assembly sequence of turn signal switch set. Table 3 shows the model elements and theirs functions.

Table 4 shows the automaker's main parameters used in modeling the case study.

The following restrictions were imposed to the model:

- Assembly of only one model of turn signal switch set (therefore, only one assembly routine of the worker was represented);

- Minimum shift change time (thus, shift change time has no influence on the production time).
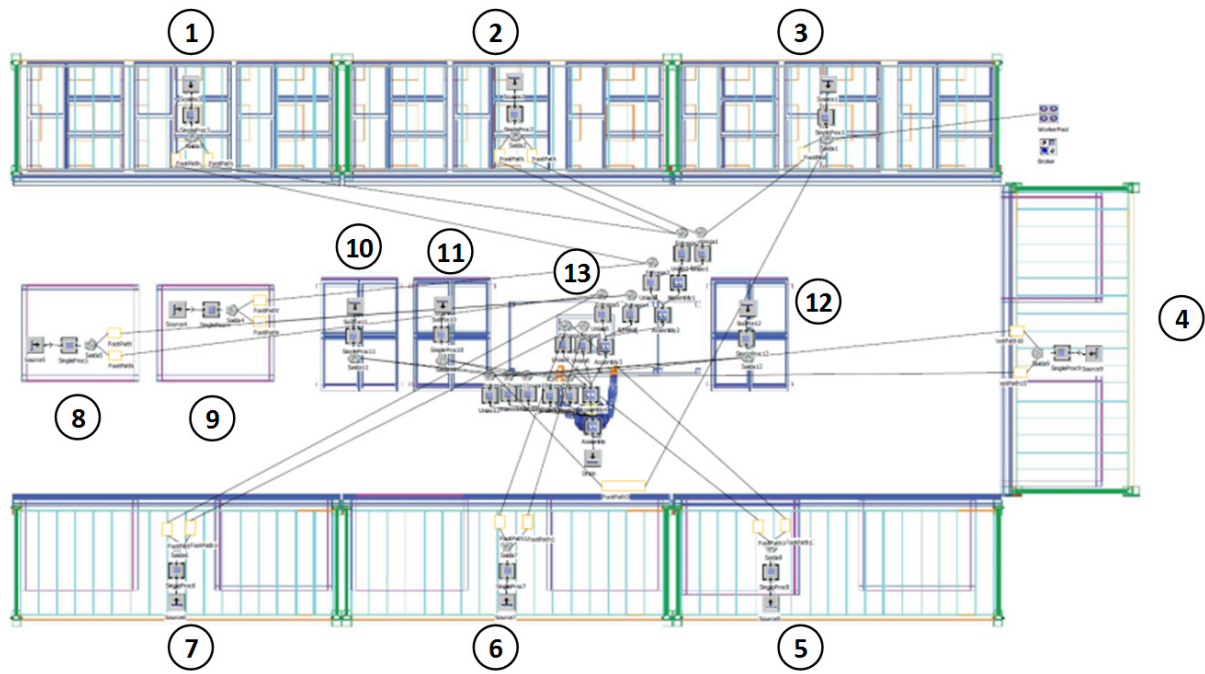
The same manufacturing cell design presented in Figure 1 was used as basis to develop the model and determine parts positioning. Therefore, the entities and

Figure 1. Manufacturing cell (adapted from SILVA and KAMINSKI, 2015).
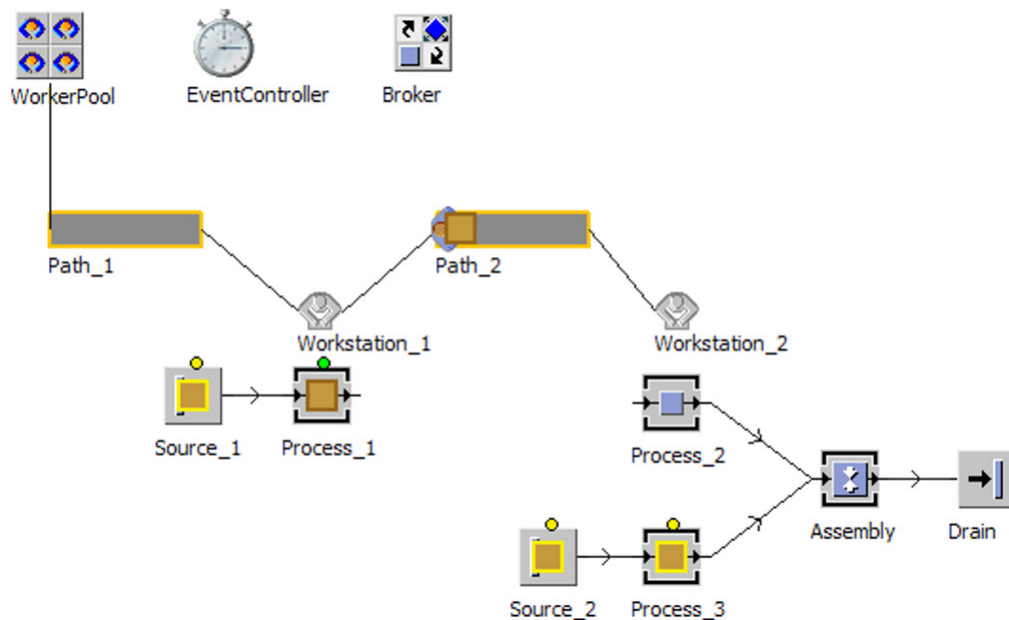
Figure 2. Detailed model developed using Tecnomatix Plant Simulation.

Figure 3. Model developed using Plant Simulation.

Table 3. Model elements and theirs functions (adapted from SIEMENS, 2016).

Icon	Name	Function
	Source	Produces Mus in a single station
	Single proc	Single station for processing a part
	Assembly station	Adds add-on parts to a main part
	Drain	Removes the parts and workpieces
	Connector	Stablishes material flow connections
	WorkerPool	Represents the lounge or the staff room of installation
	WorkPlace	Refines the Broker importer and Exporter concept
	Broker	Cooperates with the exporter and the importers of the SingleProc
	Worker	represents a working person who performs a job on a Workplace
	EventController	Coordinates and syncronizes the different events place during a simulation run
	FootPath	simulate walking distances between WorkerPool and work stations or between the stations

their respective parameters were placed obeying the same configuration of the physical cell. Figure 3 shows the model developed. The elements used in the modeling are presented and explained in Table 5.

After finishing the model, the compatibility of results provided by the model was analyzed, compared to the automaker's real production values.

4. Results analysis

Using parameters of Table 4, the model provided a result of 959 sets produced in 24 hours. The result is very close to the expected production (950 sets per day). Moreover, the difference between expected value and resulting value can be justified by the restrictions proposed initially. The statistics results for an 8-hour operation shift are showed in Tables 6 and 7.
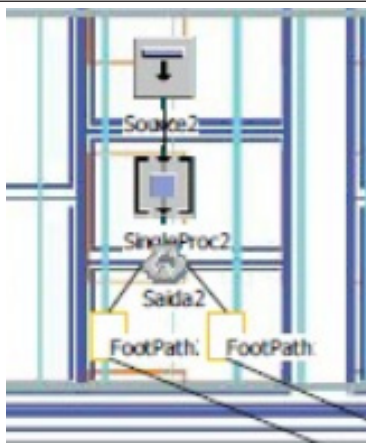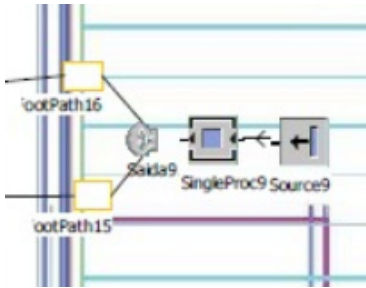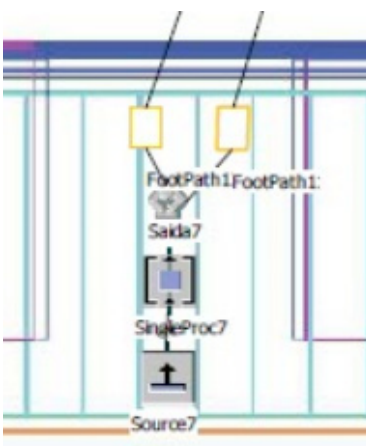
Table 4. Case study parameters.

Parameters	Values
Production volume	950 cars
Mean distances covered	1.2 meters
Operator efficiency	90%
Operator's footpath speed	1.67 m/s.
Time of operation cycle	1 minute
Work hours	24 hours.

Table 5. Elements used in the modeling.
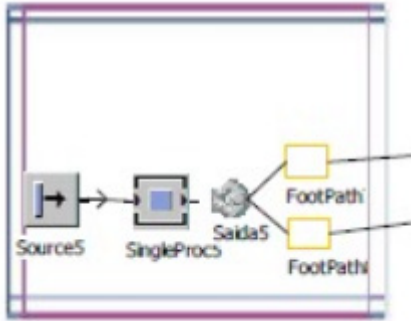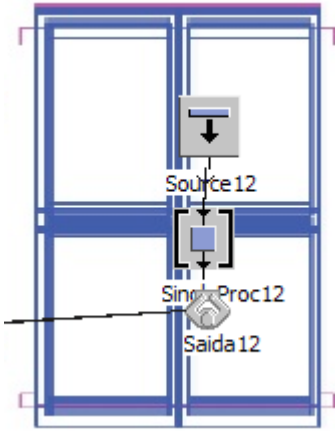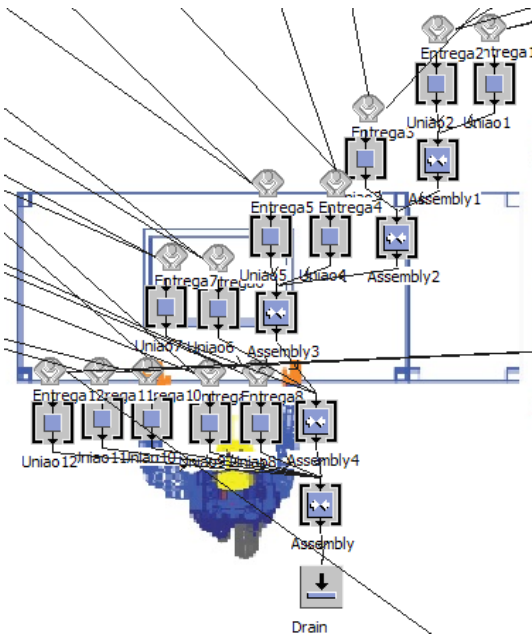
Storage position	Icons/Model	Name	Function
1 2 3		Source SingleProc WorkPlace Connectors FootPath	
4		Source SingleProc WorkPlace Connectors FootPath	Simulate a withdrawal of parts from the contaier and the moviment of the worker from the container to the workstation
5 6 7		Source SingleProc WorkPlace Connectors FootPath	

Table 5. Continued...

Storage position	Icons/Model	Name	Function
8		Source SingleProc WorkPlace Connectors FootPath	Simulate a withdrawal of parts from the contaier and the moviment of the worker from the container to the workstation
9			
10		Source SingleProc WorkPlace Connectors	
11			
12			
13		WorkPlace AsemblySation FootPath Connectors Drain	Simulate the assembly of the the signal switch set

Table 6. Statistics concerning the assembly cell.

Statistics	Values
Mean production value	1 minute and 30 seconds
Number of sets produced	320 sets

Table 7. Statistics concerning the worker.

Statistics	Values
Transportation time	78 minutes and 20 seconds
Assembly time	401 minutes and 40 seconds
Mean assembly time per set	1 minute and 15 seconds
Distance covered	7850.40m

According to the model about 83% of the worker's working time is intended for his main activity, the assembly of the signal switch set. The other 17% of his time refer to the transportation of parts for the workstation. These data to assess worker productivity in performing its main activity assembly. It can also be seen that during the 8 hours working journey the worker walked 7850m.

With de data from the model is possible to assess the distribution of the labor work throughout the working journey. The data is also a source of information for future optimization of the cell's layout to increase worker productivity and improve working conditions.

5. Conclusions

This work presented the application of a resource of Digital Factory (DF) in the study of man-machine interaction in an automotive manufacturing process. To this end, a theoretical background and a real case study based on a manufacturing cell in an automaker in Brazil were developed. The restrictions imposed to the model were adequate, and the results presented significant adherence to the expected values in a real case.

In an 8-hour shift, 320 turn signal switch sets were produced, a value close to the expected one. In addition, mean production time is 1 minute and 30 seconds, a value also in line with reality. The parameters concerning the worker are within expected magnitude, however mean assembly time per set was shown to be a little higher than what was expected: mean assembly time in a real cell is approximately 1 minute.

Analysis of operator's micromovements in the same manufacturing cell is recommended for future studies. Thus, the results can be compared with the content of this work, and new information can be identified. Such works contribute to the improvement of product development process and automotive manufacturing, and can also be used as parameters in new automotive engineering designs.

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