https://doi.org/10.4322/pmd.2018.003

Use of the Digital Factory for simulation and analysis of working methods in automotive manufacturing cell

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Abstract: The Digital Factory (DF) can be defined as a set of software oriented to the development of production processes, from the design and planning to the implementation of such processes. This work presents an update of a theoretical background and applications of DF concepts for modeling in a virtual environment of an automaker's manufacturing cell. In this cell, the operator assembles a turn signal switch of different car models, which requires him to move and bring the assembly components to a workbench. Tecnomatix Jack ergonomics software was used to simulate three methods of displacement of an avatar with Brazilian height and weight parameters, with a cycle time of one min as a boundary condition. The results in terms of cycle time (s) and metabolism (kcal) are presented and analyzed.

Keywords: Digital Factory; digital human models; human-machine interaction

1. Introduction

Product Development Process (PDP) can be defined as a set of activities organized in macrophases and phases arranged in a sequence that encompasses product concept, product development and manufacturing process, manufacturing and product distribution in the market (SILVA; KAMINSKI, 2017). Support systems for PDP activities use virtual and physical systems.

Several computational systems are used in the automotive PDP. Computer-aided design (CAD) systems and computer-aided engineering (CAE) systems are an example (WEBER, 2009) and (CHANDRASEGARAN et al., 2013). Likewise, in the virtual development of the resources needed to produce a car, there is an application of composite systems, which combine, for example, the use of CAD/CAE systems in the Digital Factory (DF) (SILVA; KAMINSKI, 2014).

DF includes validation from product development to manufacturing planning. DF can also be defined as the generic term for a network comprising digital models, methods and tools - including 3D simulation and visualization - integrated by a continuous data management system (VEREIN…, 2008).

Increased industry and government investments in human model research and development are driven by the corporate vision of increasing application and scope in virtual manufacturing, resulting in decreased physical hardware constructs and consequently lowering costs (WEGNER et al., 2007). The digital manikin is modeled representing a man at work, with its anthropometric and biomechanical dimensions. Analyses represent the interactions of the digital manikin with the virtual environment, in which the human model is positioned in its workplace and has the postures reproduced (SANTOS et al., 2016).

This work applies one of the digital simulation tools in a case study of component assembly in a manufacturing cell, aiming the analysis of the most appropriate method considering operator's ergonomics (through the analysis of metabolic values) within a predetermined cycle time.

This work is divided into eight sections. Section 1 introduces the reader to the DF theme. Sections 2 and 3 present the methodology and results of the theoretical background, respectively. Section 4 presents the concepts and fundamentals used in the case study, which is defined in Section 5. The results of the case study are presented in Section 6. In Section 7 the results obtained are analyzed. Finally, Section 8 presents the conclusion.

2. Methodology

For theoretical research, the methodology suggested by Silva and Kaminski (2016) was used. Figure 1 presents the six steps for research development.

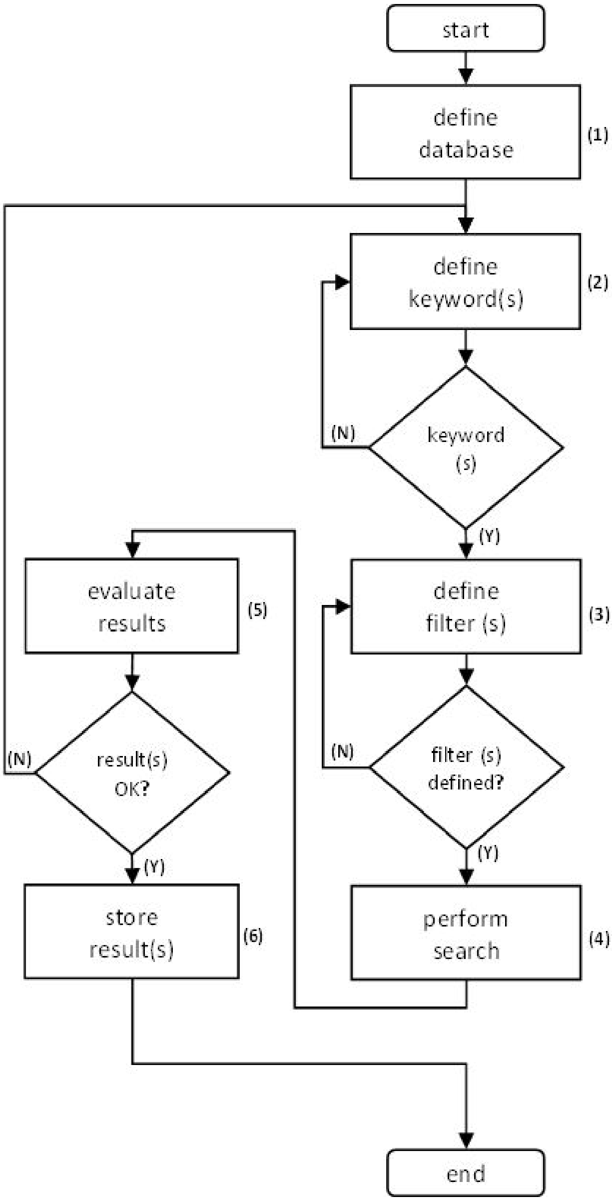


Figure 1. Search flowchart (SILVA; KAMINSKI, 2016).

Table 1 shows the consolidation of the information used in the research, using the method described.

3. Theoretical background

The theoretical basis on DF developed by Bracht, Geckler and Wenzel (2011) and updated by Silva, Kaminski and Gruber (2014) and Silva, Souza and Kaminski (2016) was complemented with Digital Human Modeling (DHM).

The consolidation of the theoretical background can be seen in Table 2.

4. Concepts and fundamentals applied in the case study

Table 3 presents the application of concepts regarding fundamentals of the theoretical background in the case study.

5. Case study

The case study is based on a real automotive manufacturing cell from a European assembler branch installed in Brazil. In this cell, the operator assembles a turn signal switch of different car models, which requires him to move and bring the components to the workbench (Figure 2).

Input parameters for the simulation are data from the automaker and are shown in Table 4.

Figure 2. Manufacturing cell, adapted from Silva and Kaminski (2014).

Table 1. Search steps and information used.

Search steps		Information used
1	Define database	Science Direct (2016) Springer Link (2016) Scopus (2016)
2	Define keywords	human-machine interaction in manufacturing systems digital factory digital manufacturing in automotive sector Digital Human Modelling
3	Define filter(s)	Content: articles. Knowledge area: computer science, engineering. Publication year: 2006-2017.
4	Perform search	Databases used: Science Direct, SpringerLink and Scopus
5	Evaluate results	Criteria: adherence to the research subject and publication impact.
6	Store results	Resource used: Mendeley*

*Mendeley® is an Elsevier's reference manager that enables to find, create and share publications.

Table 2. Theoretical background.

Author	Main subject
Silva and Kaminski (2017)	Automotive Product Development Process (PDP)
Santos et al. (2016)	Comparison between the real human and the digital human model in Delmia software using sensors
Silva, Souza and Kaminski (2016)	Classification of influential publications with the theme Digital Factory and Industry 4.0
Deuse et al. (2016)	Customizable digital human model for assembly system
Silva and Kaminski (2016)	Study of the transition from traditional Embedded Systems - ES to Cyber-Physical Systems - CPS
Polásek, Bures and Simon (2015)	Comparison between ergonomic software
Ou and Zou (2015)	Tools and applications of DF
Choi, Kim and Noh (2015)	Planning, design and application strategy of DF in real industries
Silva and Kaminski (2014)	Digital factory concepts manufacturing cells design
Silva, Kaminski and Gruber (2014)	Investigation of available DF resources in the analysis of workforce
Siemens (2014)	Applications of Siemens' Tecnomatix software package in an automotive company
Krückhans and Meier (2013)	Communications between real and virtual DF components in a plant structure
Chandrasegaran et al. (2013)	Computational tools, collaborative engineering and product development
Américo and António (2011)	Models of factories
Bracht, Geckler and Wenzel (2011)	Link between product development and production planning
Kim et al. (2010)	Assistant to digital factory
Weber (2009)	Automotive PDP, Strategic planning of vehicle manufacturing
IBGE (INSTITUTO..., 2010)	Brazilian anthropometric profile
VDI (VEREIN…, 2008)	Guidelines and foundations
Wegner et al. (2007)	Discussion on the requirements of the automotive industry and the associated standardization of digital human modeling software
Marczinski* (2006)	Computer-aided engineering tools
Wiedahl* (2003)	computational model
Westkämper et al.* (2003)	Information model
Wenzel et al.* (2003)	Digital models connected to the network Methods and tools
Maropoulos (2003)	Digital enterprise technology (DET)
Bley and Franke* (2001)	models management; exchange of information; knowledge management
Dombrowiski et al.* (2001)	virtual model of the real plant to be used; mapping of all project resources; computer-aided factory processes

*apud Bracht, Geckler and Wenzel (2011).

Table 3. Concepts and fundamentals.

Author(s) /Year	Concepts /fundamentals	Case study
Polásek, Bures and Simon (2015)	Comparison of DF tools	Selection of Tecnomatix Jack software
Silva and Kaminski (2014)	Application of tools in DF	Selection of case study
IBGE (INSTITUTO..., 2010)	Anthropometry data	Avatar setup
Siemens (2014)	Tecnomatix Jack software tutorials	Modeling and simulation
Deuse et al. (2016)	Human digital model customization	Avatar setup
Silva, Souza and Kaminski (2016)	Application of DF tool in real case study	Boundary conditions of the simulations

Table 4. Boundary conditions, adapted from Silva, Souza and Kaminski (2016).

Parameters	Value
Production volume	950 cars
Mean distances covered	1.2 m
Operator's footpath speed	1.67 m/s
Time of operation cycle	1 minute

The turn signal switch set, located behind the steering wheel and assembled next to the steering column, is responsible for turning on/off the windshield wiper, the turn signal switch and the hazard light. The set has thirteen components that are packed in twelve shelves (Table 5).

To assemble the turn signal switch, the operator needs to walk along the manufacturing cell picking up the components and bringing them to the workbench in which the components are adjusted.

The purpose of the case study is to compare, using computer simulation, three methods of displacement using an avatar with Brazilian anthropometric height and weight parameters. Parameters of 1.73 m of height and 73 kg of weight were obtained from IBGE (Brazilian Institute of

Table 5. Location of components in manufacturing cell.

Storage position	Component	Shelves
1	Lining	I
2	Lower Cover	II
3	Upper Cover	III
4	Steering Column	IV, V, VI, VII, VIII, IX
5	Switch	X
6	Box Panel	XI
7	Storage Compartment	XI
8	Lining	XII
9	Mount	XII
10	Fuse	XII
11	Clamp	XI
12	Bolt and washer	XI
13	Bolt	XII

Table 6. Different methods of worker's displacement in the manufacturing cell.

Method 1	Method 2	Method 3
I	V	I
II	VI	VI
III	VII	V
IV	IV	IV
V	I	III
VI	II	II
VII	II	II
VIII	III	I
IX	III	I
X	III	I
XI	II	II
XI	II	II
XII	III	I

Geography and Statistics) data between 2008 and 2009, considering a mean height and weight for a 20 to 34 years old population (INSTITUTO…, 2010).

Roman numerals shown in Table 6 are the locations in which the components of the turn signal switch set are packed (Figure 2 and 3). They are shown in the order the avatar must follow to pick up each component.

In this case study, Siemens' Tecnomatix Jack software was used. Figure 3 is a modeling of the manufacturing cell scenario in the software used.

For the simulation of the three methods, tutorials present in the chosen software platform were initially studied. Standard models in the software library were consulted and simple simulations and tests were developed for familiarization.

The software features a simulation module called Task Simulation Builder (TSB) that employs high-level commands to instruct the human model in virtual work

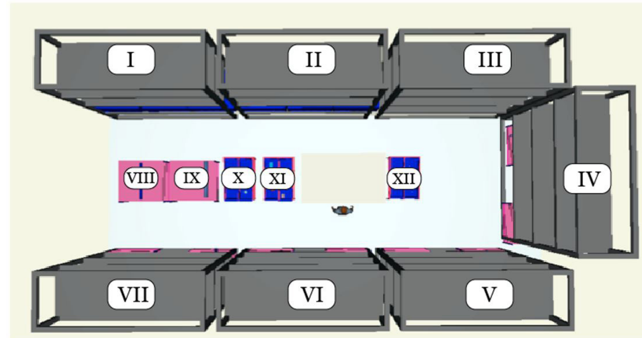


Figure 3. Manufacturing cell with shelf numbers.

environments. As a result, the simulation provides ergonomics and time reports for each operation. Table 7 presents the functions of this module used in the simulation of the three methods.

6. Results

Table 8 shows the time (in seconds) required for the avatar to perform each function according to the Methods 1, 2 and 3.

The metabolism values (in kilocalories) according to the functions performed by the avatar are shown in Table 9.

7. Analysis of results

Model calibration was performed with the boundary conditions: cycle time of one minute. The avatar was duly calibrated with Brazilian parameters of height (1.73 m) and weight (73 kg). The efficiency of the operator was not adjusted, and this adjustment was made indirectly through the time the functions were performed.

For the "Go" function, which measures the displacement time from the workbench to the shelves, Method 2 presented the lowest value and therefore was the most efficient in this regard.

For the "Get" and "Put" functions, Method 2 required more time in relation to picking up the components from the shelf and placing the components on the workbench.

Method 1 was the only one that required the operator to pick up the steering column with the "Regrasp" function, since in this method the operator takes a component by displacement using both hands.

Most of the metabolism values of Method 1 were higher relative to the other methods. This occurred because in this method the operator traveled by distant trajectories in a short period of time not to exceed the cycle time of one minute.

Method 2 was concluded to be the most appropriate, due to its lower total metabolic value, causing less distress on the person. It is also worthwhile to mention that Method 2 has a lower value for the "Bent" function that, in addition to not adding any value to the product, impairs the worker.

Table 7. TSB module functions used in the case study.

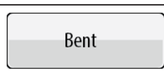
Icon	Name	Function
	Go	Go from a starting point to an end point. It is also possible to adjust the locations to which the avatar must pass previously.
	Get	The avatar picks up a selected object.
	Put	The avatar puts the object in its hand in some place.
	Regrasp	The avatar takes possession of the object using both hands.
	Standing	The avatar is standing.
	Bent	Avatar bent or in curved posture.

Table 8. Performance time of each function (in seconds).

Function	Method 1 (s)	Method 2 (s)	Method 3 (s)
Go	43.0	41.0	43.3
Get	9.7	10.1	8.0
Put	7.0	8.9	8.7
Regrasp	0.3	0	0
Total	60.0	60.0	60.0

Table 9. Metabolism values (in kilocalories).

Function	Method 1 (kcal)	Method 2 (kcal)	Method 3 (kcal)
Go	9.667	3.168	4.191
Get	0.216	0.125	0.103
Regrasp	0.175	0.147	0.188
Put	0.001	0	0
Standing	1.547	1.632	1.619
Bent	0.246	0.145	0.16
Total	11.852	5.217	6.261

8. Conclusion

This work presented the application of a resource from Digital Factory (DF) in the study of human-machine interaction in a manufacturing cell of an automaker in Brazil.

A theoretical basis was developed and main fundamentals and concepts studied were applied in the modeling of the manufacturing cell in Siemens' Tecnomatix Jack software. The boundary conditions imposed on the model were adequate and the results were consistent with the values expected in a real case.

For future studies, analysis of the efforts in the muscular groups of the worker's spinal cord is suggested to discuss more efficient methods. Such analysis can be performed through the results also obtained using Siemens' Tecnomatix Jack software.

9. Acknowledgements

The authors thank FUSP (Fundação de Apoio à Universidade de São Paulo) and the Centro de Engenharia Automotiva (CEA) of the Escola Politécnica da Universidade de São Paulo for the support.

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