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.
The table below shows the consolidation of the information used in the research, using the method described.

### Table 1. Search steps and information used.

<table>
<thead>
<tr>
<th>Search steps</th>
<th>Information used</th>
</tr>
</thead>
</table>
| Define database | Science Direct (2016)  
                   Springer Link (2016)  
                   Scopus (2016) |
| Define keywords | human-machine interaction in manufacturing systems  
                  digital factory  
                  digital manufacturing in automotive sector  
                  Digital Human Modelling |
| Define filter(s) | Content: articles.  
| Evaluate search | Databases used: Science Direct, SpringerLink and Scopus |
| Store results | Criteria: adherence to the research subject and publication impact. |

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

### 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.
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.

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

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

<table>
<thead>
<tr>
<th>Method 1</th>
<th>Method 2</th>
<th>Method 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>V</td>
<td>I</td>
</tr>
<tr>
<td>II</td>
<td>VI</td>
<td>VI</td>
</tr>
<tr>
<td>III</td>
<td>VII</td>
<td>V</td>
</tr>
<tr>
<td>IV</td>
<td>IV</td>
<td>IV</td>
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<tr>
<td>V</td>
<td>I</td>
<td>III</td>
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<td>VI</td>
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<td>II</td>
</tr>
<tr>
<td>VII</td>
<td>II</td>
<td>II</td>
</tr>
<tr>
<td>VIII</td>
<td>III</td>
<td>I</td>
</tr>
<tr>
<td>IX</td>
<td>III</td>
<td>I</td>
</tr>
<tr>
<td>X</td>
<td>III</td>
<td>I</td>
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<tr>
<td>XI</td>
<td>II</td>
<td>II</td>
</tr>
<tr>
<td>XII</td>
<td>III</td>
<td>I</td>
</tr>
</tbody>
</table>

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 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.
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

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