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Research paper

Trends in Modeling and Simulation in the Automotive Industry Concerning the Bond Graph framework

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Abstract

Modeling is a process by which an experiment (organized way of obtaining data) can be applied to answer questions about a system; taking into account that a system, in summary, is a potential source of data and a simulation is the experimentation of the possible behavior of a system in a model. Both (modeling and simulation) are processes to develop and test theories in many fields of application of engineering. This paper presents a study of trends in modeling and simulation concerning the Bond Graph reference framework, carried out through an analysis based on bibliometric maps. The results show a strong connection between simulation models and the automotive industry in the frame of reference Bond Graph.

Keywords: *Automotive Industry; Bibliometric Maps; Bond Graph; Modeling; Simulation*.

1. Introduction

Today, in any field of engineering, modeling and simulation are essential, during the last decades these processes have been used to answer questions of a new project, to implement new devices or to experience possible behaviors of a system.
The modeling of engineering systems at a general level can be used to analyze, perform tests, specify input data, execute, and study behaviors before changes in a structure among other activities [1-3]. The multidisciplinary nature of simulation and modeling makes its application combine methodological developments to various fields of application, thus offering extensive possibilities to scientists [4, 5].
Considering the mentioned uses of modeling in engineering, we can say that simulation is the experimentation of the possible behavior of a system within a model.
The simulation has multiple applications in the automotive industry such as the design of new systems or the re-design of existing systems [4]. There are several investigations on applications of simulation and modeling in automobiles, for example, Singh et al. [6] use a new strategy for shifting gears in an automated manual transmission with a mathematical model. Abduaziz et al. [7] apply simulation methods to assess green logistics practices in the automotive industry. Vedrtnam [8] use modeling to find the variation of drag coefficient among other aerodynamic aspects in a vehicle. Cerri and Terzi [9] carry out procedures to design and model a product-service system in the automotive industry. Sokil et al. [10] evaluate by modeling the effect of the relative motion of the cushion system in automobiles. Dengiz et al. [4] perform optimization processes through simulations based on a meta-model to increase productivity in the automotive industry.
In the same way, there are investigations where in addition to using simulation and modeling, prediction, experimental validation, and verification are also used [11 - 13], as well as the use of computational analysis and industrial robots [14, 15] , structural and functional aspects such as the brake system, water tank, suspension system, car data management system are also analyzed through modeling and simulation [16 - 19], and we can also mention the use of simulations to study models that favor the reduction of emissions and fuel consumption [20].
Due to recent studies on simulations and modeling in the automotive industry, this article presents a study of trends in modeling and simulation concerning the Bond Graph reference framework, carried out through an analysis based on bibliometric maps. The results show a strong connection between simulation models and the automotive industry in the frame of reference Bond Graph.

2. Methods and materials

The methodology used for the research consisted as the first step in a systematic review of the literature to identify trends in modeling and simulation in the automotive industry concerning the Bond Graph framework; for which the specialized databases IEEE Xplore, Science Direct, Scopus, Web of Science and the Google Scholar metasearch engine were selected as reference sources. Articles and books included in the last decade were taken into account, as well as search strings to limit the information found such as Bond Graph AND Automatic Control, Bond Graph AND Automotive, Bond Graph AND Modeling AND Simulation, Bond Graph AND Modeling Automotive.
The second step was an analysis based on bibliometric networks and cluster techniques where using the same search strings mentioned and using the VOSviewer® software. Bibliometric maps were created taking into account aspects such as co-authorship, the co-occurrence of keywords, citations, and others [21-23]; for the characteristics of this research, the keyword co-occurrence technique is used because it is investigating recent trends and the level of connection between them. The use of bibliometric networks are techniques that can be associated with data mining because a data

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exploration is also carried out to find patterns in large volumes of data [24].

The bibliometric analysis consists of a network of nodes *n*, where *Lij* corresponds to the number of links referring to the co-occurrence of terms between nodes *i* and *j*, where $Lij = Lji \geq 0$. *Sij* corresponds to the strength of association of the nodes *i* and *j* [22, 23] and is given by:

$$S_{ij} = \frac{2nL_{ij}}{L_i L_j} \quad (1)$$

Where *Li* and *Lj* correspond to the total number of links of the nodes *i* and *j* respectively, and *n* corresponds to the total number of links in the bibliometric network, with which,

$$L_i = \sum_{j \neq i} L_{ij} \qquad and \qquad n = \frac{1}{2}\sum_{i} L_i \quad (2)$$

3. Results and discussion

The analysis of bibliometric maps is carried out considering the co-occurrence of keywords in order to visualize the recent trends in modeling and simulation in the automotive industry concerning the Bond Graph framework. In this investigation, we use the normalization of co-occurrence of data called Strength of Association, which is more appropriate than the cosine and Jaccard indices [25, 26].

With the use of VOSviewer® software [23] and the techniques discussed above, the following bibliometric map is made. Figure 1 shows the graphical result of the co-occurrence of keywords, where it can be seen, for example, that the words "performance," "control," "hydraulic system," "simulation model" have a strong presence, with several links between them and other words. Which indicates preliminarily that currently in the modeling and simulation regarding the frame of reference Bond Graph the tendency or what more is working is on the mentioned words: performance, control, and hydraulic system.

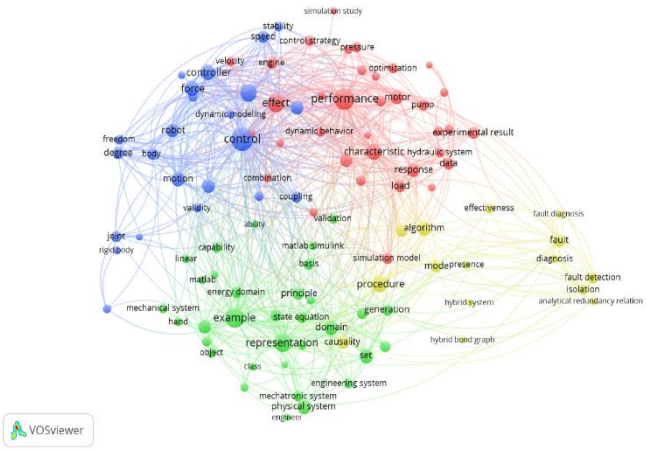

Fig. 1: Bibliographic map for modeling and simulation in the automotive industry concerning the Bond Graph framework.

Considering that to analyze the Bibliographic Map the technique of "Association Force" is being used, then, in the following tables, strong relationships are observed between each of the keywords with a strong presence of Figure 1. A higher number means a higher strength of association between the keywords, that is, these words appear more often together in the research results.

In Table 1, the word "Simulation Model" is compared to the other words in the bibliographic map, in which it can be seen that with the words that the association forces are with "performance" with a value of 12, "control" with a value of 9, "hydraulic system" with a value of 8 and so on.

Table 1: Strength of association with "Simulation Model"

Strength of Association	Simulation Model
Performance	12
Control	9
Hydraulic System	8
Block Diagram	7
Physical System	7
Bond Graph Theory	7
Vehicle	6

In Table 2, the word "Vehicle" is compared to the other words in the bibliographic map, in which it can be seen that with the words that the association forces have is "control" with a value of 42, "performance" with a value of 23, "controller" with a value of 22, "optimization" with a value of 13, and so on.

Table 2: Strength of association with "Vehicle"

Strength of Association	Vehicle
Control	42
Performance	23
Controller	22
Optimization	13
Mechanism	10
Motion	10

In Table 3, the word "Control" is compared to the other words in the bibliographic map, in which it can be seen that with the words that the association forces are with “controller” with a value of 53, “performance” with a value of 47, “vehicle” with a value of 42, “robot” with a value of 39, and so on.

Table 3: Strength of association with "Control"

Strength of Association	Control
Controller	57
Performance	47
Vehicle	42
Robot	39
Control Strategy	29
Motor	26
Stability	17

These analyzes are useful because they show the current scenario and future trends in the modeling and simulation in this case for the automotive industry and to be able to make essential decisions on what issues to address in new investigations [27-33]. In the same way, the institutes of technical education and universities could update their curricula in the area of electronics, automation and modeling and simulation [34-45].

4. Conclusion

After analyzing some characteristics of future trends in modeling and simulation in the automotive industry concerning the Bond Graph framework. Specifically, in the analysis of bibliometric maps, it is found that the simulation models have a strong connection, that is, they are using quite often to measure the performance, to apply control systems, to optimize the operation of the automotive industry. Similarly, strong connections were found with robotic systems in the field of computational analysis and industrial robots and also functional aspects of the vehicle, all of the above regarding the frame of reference Bond Graph.

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