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Trend of Scientific research: Analysis of Mega-data of discrete event systems described by mathematical tools

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***Abstract* _In this article, we are interested in the discrete event systems modeled by the mathematical tools (Boolean algebra, state space, max-plus, algebra process, temporal logic) and we analyze the mega-data of more than 800 articles published in the last forty years to evaluate the maturity level and determine the trend of the scientific research in this domain.**

Keywords: Discrete event systems, Mathematical tools, Trend of scientific research.

I. INTRODUCTION

Discrete event systems denote systems typically human conception as production systems, transportation networks and computer systems. Their evolution obeys the occurrence of events that occur at discrete times.

The class of discrete event systems has been widely studied in the literature [1-4]. His interest is justified by the existence of a large number of real systems evolve to the occurrence of events. Many mathematical tools (Boolean algebra, state space, max-plus, algebra process, temporal logic) have been proposed for the study and analysis of discrete event systems [5-10]; to obtain adapted models for their description and their order.

Given the diversity and multitude of these mathematical tools, researchers are faced to the confusion of choosing the most appropriate tool. The present work aims to build a database, by the treatment of more than 800 existing articles in the domain of discrete event systems during the last four decades, in order to determine the tool that constitute an axis of active, open, and scalable research.

This article is going to focus only on mathematical tools. Other modeling tools (Petri networks and automata) are the subject of [11, 12].

This paper is organized as follows: In the second section we recall the different notions on discrete event systems and some definitions of key words used along this article. The third part is devoted to the problematic and the methodology used for the classification of articles. The fourth section represents discussions for the results obtained and the last one concludes the paper.

II. TERMINOLOGY

This section presents some important reminders terminologies in the field of discrete event systems. The objective of this section is not to propose new terminologies, but to implement all the definitions of terms used in this article.

A. *Discrete event system*

A discrete event system is a dynamic system that evolves in accordance with the abrupt occurrence, at possibly unknown irregular intervals, of physical events. Such systems arise in a variety of contexts ranging from computer operating systems to the control of complex multimode processes[13].

B. *decision-making structure*

1. Centralized structure

The centralized approach is an approach where there is a single module of analysis or decision (supervisor or diagnostician) which collects and analyzes global information coming from the process. The figure (1) gives an example of centralized diagnostic architecture.

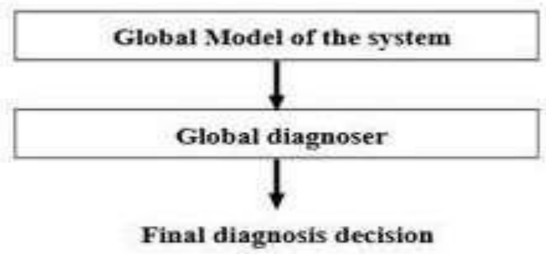

Figure 1: centralized structure

2. Decentralized structure

The decentralized approach is an approach where there is several elementary decision-making structure of the same type. Each one of these structures collects a part of the global information. The global decision is obtained by performing a functional calculus on all decisions of the elementary structures. Figure (2) gives an example of a decentralized architecture of diagnosis

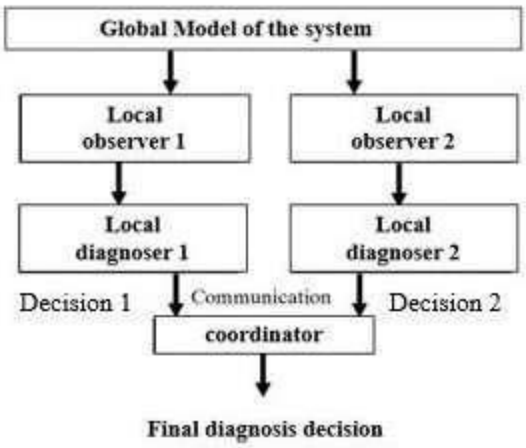

Figure 2 : decentralized diagnosis

C. Types of discrete events systems

1. Deterministic system

A deterministic system is a system which always reacts in the same way to an event. The system state is described by a well-defined process, that is to say, regardless of what happened before, from the time the system reaches a given state, its evolution will always identical. [14]

2. Non-deterministic system

As opposed to a deterministic system, a system is non-deterministic if one or more of its output variables are random variables. A probabilistic framework is required for the study of these systems.

D. Mathematical Modeling tools

1. Boolean algebra

A Boolean algebra is an algebraic structure (B, ∨, ∧, *, 0, 1), where ∨ and ∧ are binary operators, * is a unary operator, said complementation, and 0 and 1 are constants, such that for all x, y, z ∈ B, the following laws are met.

- B1 commutativity: $x \vee y = y \vee x$ // $x \wedge y = y \wedge x$
- B2 associativity: $x \vee (y \vee z) = (x \vee y) \vee z$ // $x \wedge (y \wedge z) = (x \wedge y) \wedge z$
- B3 absorption: $(x \vee y) \wedge y = y$ // $(x \wedge y) \vee y = y$
- B4 $x \vee x^* = 1$ // $x \wedge x^* = 0$
- B5 distributivity: $x \vee (y \wedge z) = (x \vee y) \wedge (x \vee z)$ or: $x \wedge (\vee z\ y) = (x \wedge y) \vee (x \wedge z)$

Called "sup" the operation noted "∨" and "lower" the operation noted "∧"; x * is said to be the complement of x. [15]

2. Max-plus

In max-plus algebra we work with the max-plus semi-ring which is the set = $\{-\infty\} \cup R$ together with operations $a \oplus b = \max(a; b)$ and $a \otimes b = a+b$. The additive and multiplicative identities are taken to be $\varepsilon = -\infty$ and $e = 0$ respectively. Its operations are associative, commutative and distributive as in conventional algebra.

Max-plus algebra is one of many idempotent semi-rings which have been considered in various fields of mathematics. One other is min-plus algebra. There ⊕ means minimum and the additive identity is ∞. [16]

3. Process Algebra

The Process Algebra have mostly been developed to model the behavior of competing processes. The notions of hierarchy, modularity, communication, abstraction and parallelism are rigorously defined in a mathematical formalism that supports algorithms evidence. Process Algebra is the formal description of systems that best express the needs of the formal verification. Indeed, they are the carrier of many of evidence tools and allow the extension to new operators.

In the semantics of process algebras, a process or an agent is seen as a black box that exchange with its environment events or actions through communication ports. The agents may be interconnected by communication channels, realized by connecting two ports of two different processes. If action is not observable by the environment, it is called internal, in which case, the process has evolved internally without communication with its environment.

4. Temporal logic

Temporal logic is an extension of the conventional logic, it includes new operators that express the notion of time. There are 2 types of temporal logic:

The linear temporal logic or LTL: used to represent the behavior of reactive systems with properties that describe the system where time flows linearly.

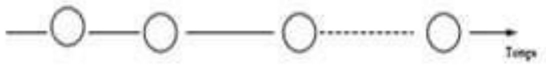

Figure 3: linear temporal logic LTL

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The tree temporal logic or CTL: allows to consider several possible futures from a state of the system rather than having a linear view of the system considered

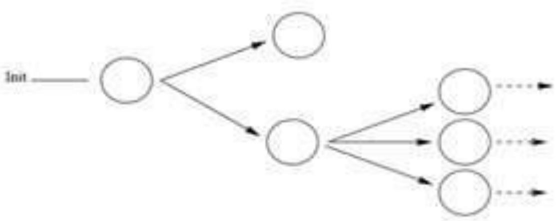

Figure 4: tree temporal logic

5. State space

The basic idea of state representations is that the future of a system depends on its past, its present and its inputs: the future can then be described from a well-chosen set of variables.

Unlike conventional analysis system that uses the representation of Laplace, in the case of the representations of state, the analysis takes place in the time domain. In fact, the framework of the analysis of the complex variable function replaces part of matrix algebra.[17]

To illustrate, consider the example in Figure 5 described by the following differential equations

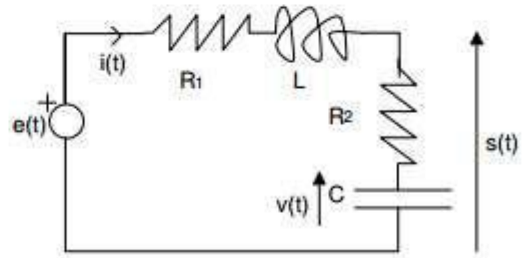

Figure 5: example of an electronic system

- $e(t) = (R1 + R2)\, i(t) + L\, {}^{di}/ + v(t)$
- $i(t) = C\ /$
- $s(t) = R2i(t) + v(t)$

E. Decision support tool

Control: The function that triggers the execution of a set of operations by giving orders to the process actuators, which may be:

- A set of operations corresponding to the manufacturing sequence of the product.
- A set of operations executed in order to restore the process functionality offered during normal execution.
- Actions with a high priority level applied in order to protect the shop workers and to prevent catastrophic developments.
- Some checking, tuning or cleaning operations executed in order to maintain the process in an operational state.[18]

Supervision: The function that computes and sets the parameters of the control sequence to be executed according to the state of the control system and to the state of the process. This includes normal and abnormal operations. During normal operation, supervision takes the decisions to raise the indecision in the control system (real-time scheduling, optimization, control sets and switching from one control law to another). When a process failure occurs, supervision takes all the decisions necessary to allow the system to resume normal operation (rescheduling, recovery actions, emergency procedures, etc.). [18]

Monitoring: The function that collects data from the process and from the controller, determines the actual state of the controlled system and makes the inferences needed to produce additional data (historic, diagnosis, etc.). Monitoring is limited to data processing and has no direct action on the models or on the process. [18]

Diagnosis: The function that looks for a causality link between the observed symptom, the failure and its origin. Classically, three sub-functions are distinguished:

- Localization determines the subsystem responsible for the failure,
- Identification identifies the causes of the failure,
- Explanation justifies the conclusions. [18]

Robustness: A system may be defined as its ability to retain the properties specified in the presence of variations or planned or unplanned uncertainties. For each system and each level in the case of a hierarchical conduct, robustness can be of two different types:

The internal robustness regarding changes in the value of the process model parameters.

The outer key strength for its variations, intentional or not acceptable to the system input.[19]

Simulation: Simulation is the activation of the model over time, in order to know its dynamic behavior and predict future behavior.

The simulation is mainly used to study the physical flows (parts, materials, tools, etc. ...) and data-processing (manufacturing orders, Kanban, etc. ...) in the workshop and the availability of resources (operators, machines, etc.) [20]

Modeling: Modeling of a physical system is a description of its structure and a behavioral or functional representation of each of its components. A behavioral representation is established by relations between different variables of the system, typically called relations of cause to effect. A functional representation is more abstract because it addresses only the presumed objectives which the physical system has to fill [21].

III. METHODOLOGY

The discrete event systems are a scalable axis of research and they have received much attention over the last four decades. The presence of multiple extensions of mathematical tools for modeling this systems (Boolean algebra, state space, max-plus, process algebra, and temporal logic) generates an enormous diversity of research areas and sets new Researchers in confusion to choose the most suitable axis to Develop.

In this paper, we propose the analysis of the mega-data base which allows the classification of over than 800 articles dealing with discrete event systems described by tools already mentioned. The establishment of this database will allow future researchers to easily start their research through:

- Statistical processing of previous publications,
- Following up the development of this discipline,
- Evaluation of the level of maturity of each mathematical tools,

The treated articles are classified initially according to the modeling tool used in each article (Boolean algebra, state space, max-plus, algebra process, temporal logic)

Then a 2nd classification is made according to other criteria:

- The structure of decision making (centralized, decentralized)
- The type of system studied (deterministic, non-deterministic)
- The decision-support tool (control, supervision, monitoring robustness, diagnosis, simulation, modeling)

After the classification, we traced the curves representing the number of articles based on their publication years. The interpretation of these curves is based on their shapes. Figure 6 summarizes all possible interpretations.

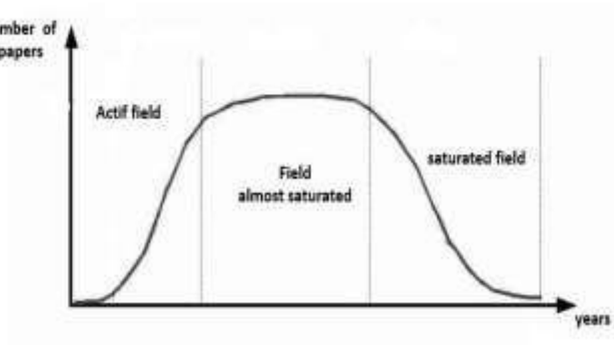

Figure 6: interpretation of curves

IV. RESULTS AND DISCUSSION

In this section we present the database established with all the results obtained.

A. *Classification by the modeling tool*

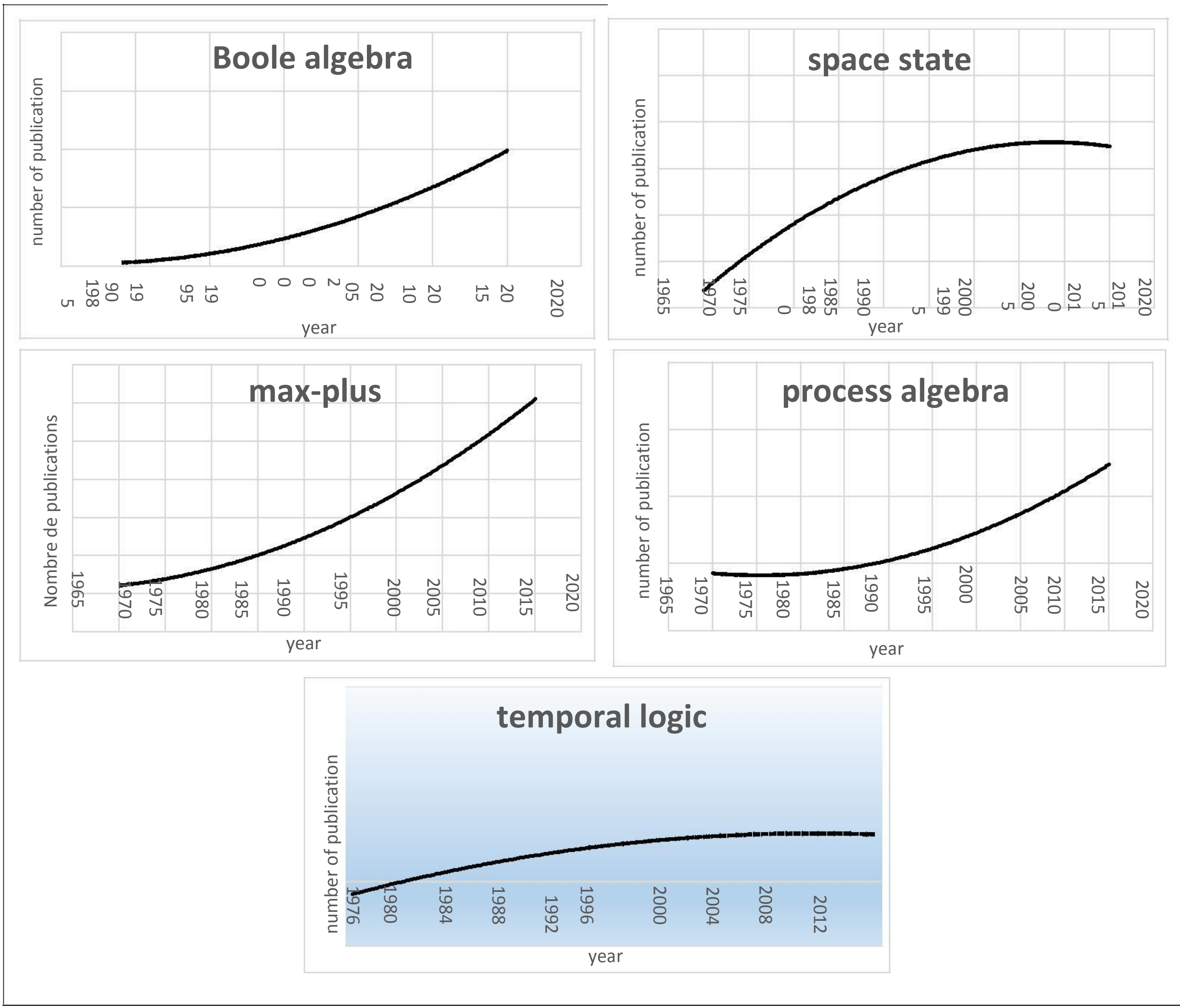

Figure 7: Number of articles published by year for each mathematical tools

Figure 7 shows the evolution of the number of articles published by years for each mathematical tools (Boolean algebra, state space, max-plus, algebra process, temporal logic).

By analyzing in detail the shape of the curves of each mathematical tools, there are two types of curves:

• Growing curve: The shape of the curves of (Boolean algebra, max-plus algebra and process) shows a strong increase in the number of published articles based on years (last 4 decades).

• Decreasing or nearly stable curve: the shape of curves of (state space, temporal logic) indicates a stabilization in the number of articles published in the 90s then a steady decline in the last decade.

Results interpretation

From the analysis of these results, we can conclude that:

Three mathematical tools (Boolean algebra, max-plus, process algebra), recorded strong growth in the number of publications, and they have received much attention from researchers over the past four decades. Therefore they can be an active center of research for future research work.

Unlike tools (state space, temporal logic) who have experienced a decline in the number of publications in recent years, which means that they are no longer a scalable axis, and the research for these tools is saturated.

In the rest of this paper only the tools that constitute active research areas will be considered:

• Boolean algebra • Max-plus • Algebra process

F. Classification by the decision support tool

Based on the above results, it was found that: Boolean algebra, process algebra, and Max-plus are a part of mathematical tools receiving much attention from researchers, and recorded a large number of articles published in recent years.

In this part we will determine the decision support tool (diagnostic, supervision, monitoring, robustness, modeling, simulation, control) most used for each of these mathematical tools.

1. Boolean algebra

Figure 8 shows the curves of the most used decision support tool for describing discrete event systems by Boolean algebra:

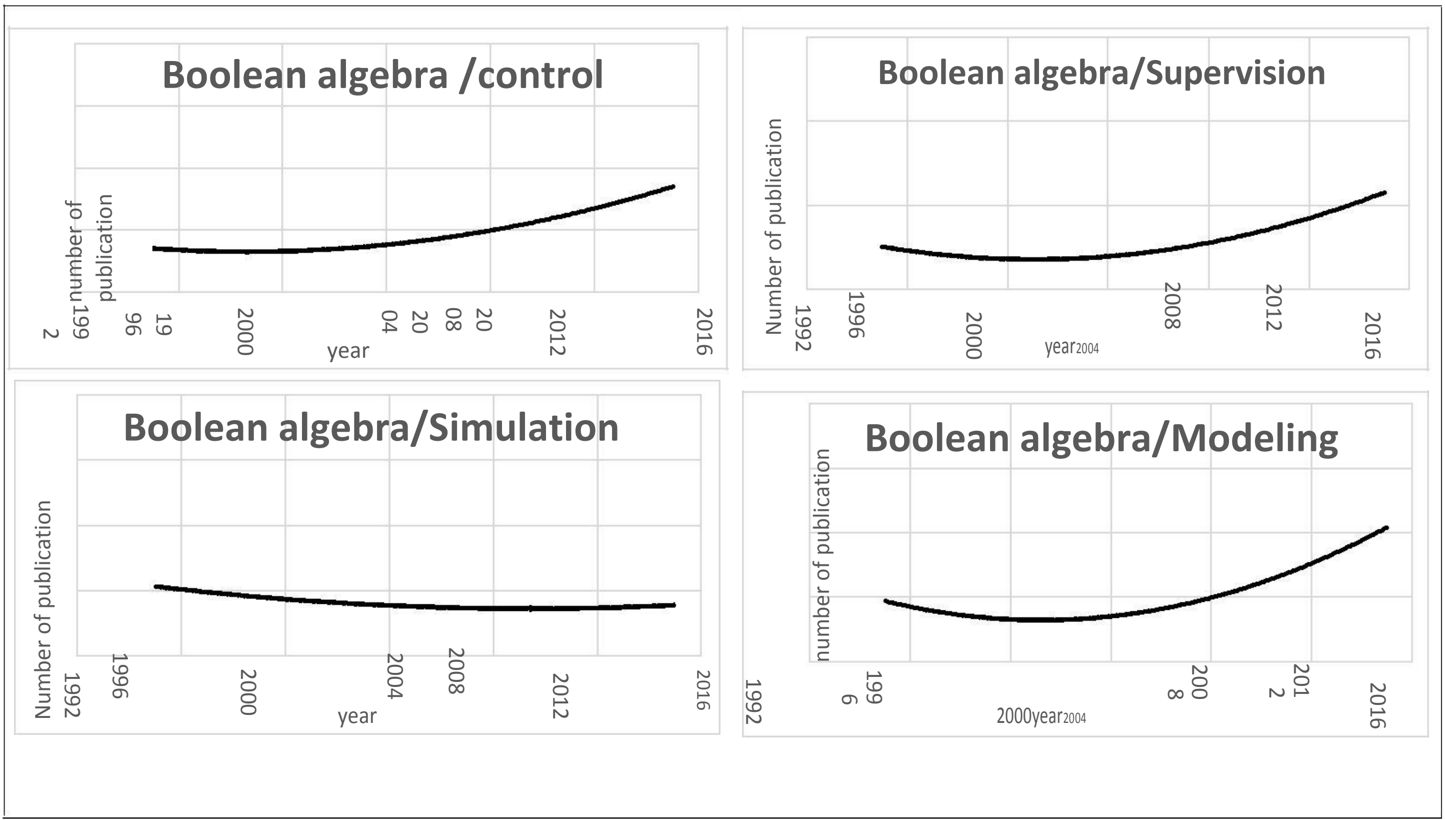

Figure 8: The most used decision support tool for boolean algebra

According to these curves, there is a rapid growth in the number of articles that discuss supervision, control, and modeling of discrete event systems by Boolean algebra. However, the insufficient number of articles that discuss (diagnosis, monitoring, robustness) related to Boolean algebra and discrete event systems, did not allow to obtain significant results about their evolution over the last 4 decades**.**

Results interpretation

By carefully examining the shape of these curves, we realize that the most used support tool for describing discrete event systems by Boolean algebra are:

▪ Supervision - Control - Modeling

2. Max-plus

Figure 9 shows the curves of the most used decision support tool for describing discrete event systems by max-plus:

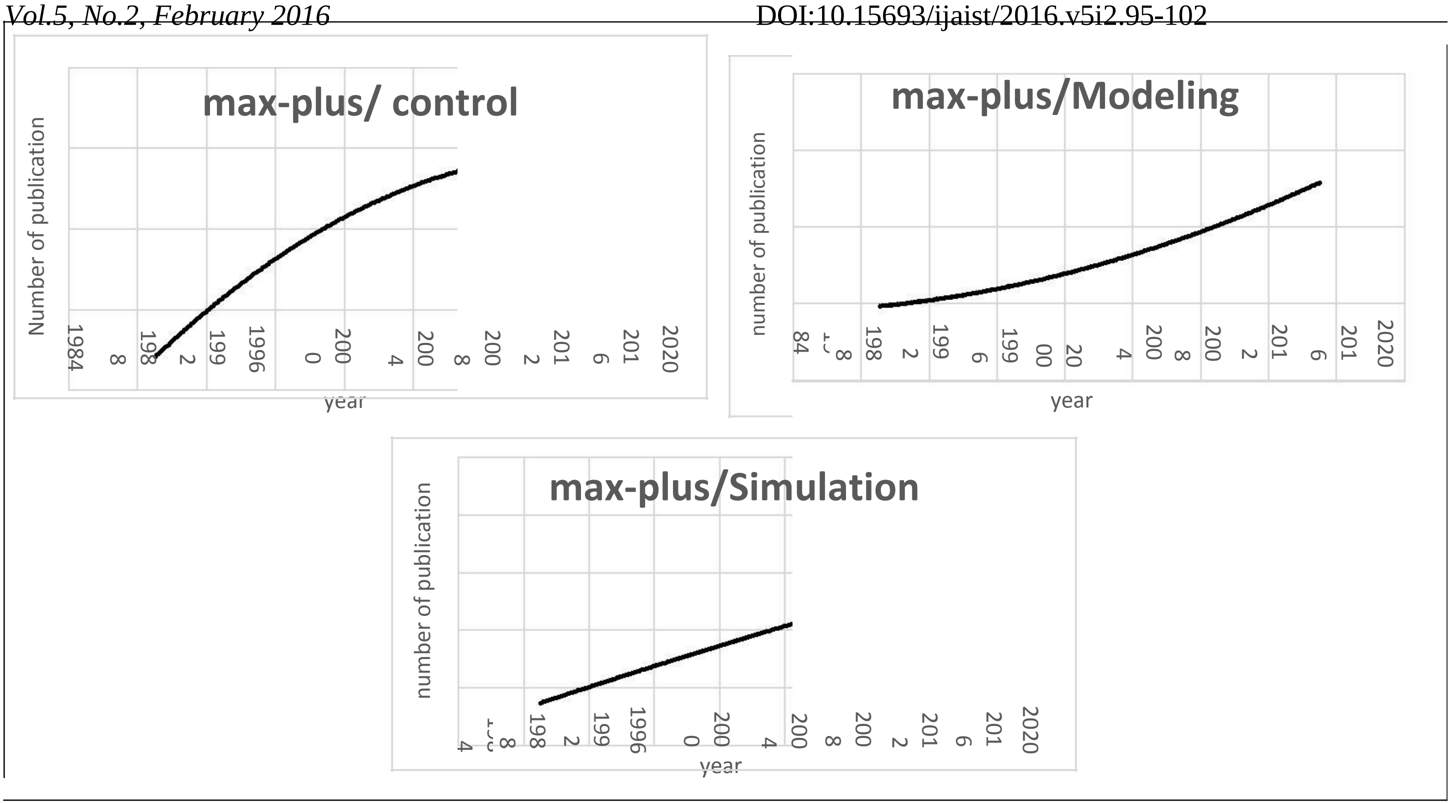

Figure 9: The most used decision support tool for max-plus

According to these curves, there is a rapid growth in the number of articles that discuss simulation, control, and modeling of discrete event systems by max-plus.

However, the insufficient number of articles that discuss (diagnosis, monitoring, robustness, supervision) related to Max-plus and discrete event systems, did not allow to obtain significant results about their evolution over the last 4 decades.

Results interpretation

By carefully examining the shape of these curves we realize that the most used support tool for describing discrete event systems by max-plus are:

- Simulation
- Control
- Modeling

3. Algebra processes

Figure 10 shows the curves of the most used decision support tool for describing discrete event systems by process algebra:

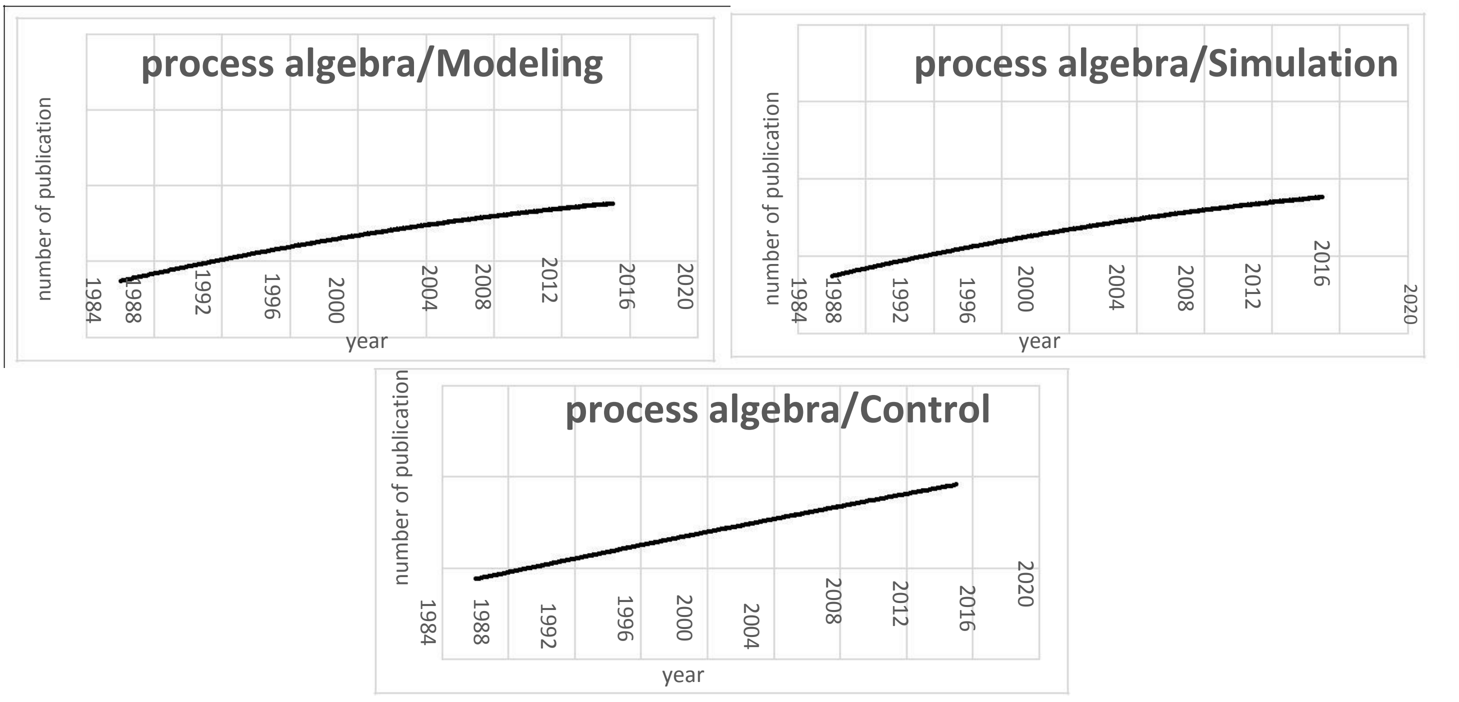

Figure 10: The most used decision support tool for process algebra

According to these curves, there is a rapid growth in the number of articles that discuss simulation, control, and modeling of discrete event systems by the process algebra.

However, the insufficient number of articles of articles that discuss (diagnosis, surveillance, robustness, supervision) related to process algebra and discrete event systems, did not allow to obtain significant results about their evolution over the last 4 decades.

Results interpretation

By carefully examining the shape of these curves we realize that the most used support tool for describing discrete event systems by processes algebra are:

- Simulation
- Control
- Modeling

G. Classification by structure of decision making

In this part we are interested in determining the structure of decision making (centralized, decentralized) most used with each of these mathematical tools, and following the trend of scientific research. The insufficient number of articles that discuss the structure of decision making, prevented us to achieving significant results about their evolution over the past 4 decades.

H. Classification by type of system studied

The purpose of this part is to determine the type of the studied system (deterministic, non-deterministic) the most used with each of these mathematical modeling tools, and following the trend of scientific research. The insufficient number of articles that discuss the type of system studied, prevented us to achieving significant results about their evolution over the past 4 decades.

V. CONCLUSION

The objective of this study was to evaluate the trends of scientific research in terms of DES processing mathematical tools. The study was conducted in three phases: 1st phase: bibliographic research on search engines already mentioned. 2nd phase: classification of publications selected in the Mega-Data base. 3rd phase: analysis of the results. The Mega-Data base allowed to note that most of the literature has focused on treatment of DES by:

- The Boolean algebras (supervision, monitoring, modeling)
- Max-plus (simulation, monitoring, modeling)
- Process algebras (simulation, monitoring, and modeling)

This work can be extended in several ways. Is it will guide and help researchers to choose the appropriate tool to describe discrete event systems according to the desired objective.

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