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Systems Science and Engineering Research in the Context of Systems, Man, and Cybernetics: Recollection, Trends, and Future Directions

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***Abstract*—To commemorate the 50th anniversary of the IEEE Transactions on Systems, Man, and Cybernetics: Systems, this paper examines and reports on its past to current topical coverage of systems science and engineering toward exploring the evolving focus of the research community. Results of a systematic bibliometric analysis are presented with associated conclusions, implications, and summary of topical areas. In addition, respective views regarding the current state of the field and where it is headed are offered by recent leaders of the IEEE Systems, Man, and Cybernetics Society, including its continued relevance and role in the advancement of systems technology.**

***Index Terms*—Systems engineering, systems science, research trends, Bibliometrics, Science mapping analysis, co-word analysis, SciMAT, H-classics, h-index**

I. Introduction

For the past half-century, this journal has served as a conduit for dissemination of new research findings and for scholarly documentation of scientific progress in the field of systems engineering. This 50th anniversary issue of the journal offers an appropriate moment to reflect on the treatment of a range of topics within systems engineering and across the breadth of systems science, including topics covered in the journal regarding human information processing concerns in systems and organizations.

Past leaders of the IEEE Systems, Man, and Cybernetics (SMC) Society have occasionally reflected on the state of the Society and the evolution of its three principal areas of technical activity – systems science and engineering, human-machine systems, and cybernetics [1]–[5]. Its acknowledged broad scope has always been considered a strength, deliberately retained over the years while persistently reflected in all aspects of the Society. This paper follows suit with a focus on the systems science and engineering area at the core of this journal's scope.

Nearly 3 decades ago, in a paper commemorating the 20th anniversary of the SMC Society [1], past Society leaders asserted that an objective supporting the multifarious nature of its broad technical scope is the ongoing development of systems engineering as an information-science and information systems-based discipline. This alludes to a contrast with a view of traditional engineering based on physical sciences, and a realization that systems science and engineering complements information science and systems, in that the former allows for the integration of physical and information bases of engineering that enables system designs that support humans.

As noted nearly 2 decades ago in a paper commemorating the Society's 30th anniversary [3], this journal has published articles in a broad range of areas since its inception, all of which are based on Norbert Wiener's interdisciplinary cybernetics concepts. It was acknowledged at that time that the techniques and concepts underpinning SMC Society fields of interest were evolving with the evolution and emergence of new technologies. That work considered the frequency of use of primary words in paper titles published in the journal years prior to offer a sense for how the technical focus has changed over the years. For example, in the early 1990s, major words used were systems and robot and by the early 2000s major words including systems, fuzzy, and control became prominent. This was seen to signify a move from non-perceptive and non-adaptive systems toward intelligent systems, that deal with uncertainty and vagueness, as a focal area for the SMC Society [3].

About a decade ago, a view of the SMC research outlook [4] considered service systems, infrastructure and transportation systems, environmental and energy systems, and defense and space systems as important application domains for the decade leading to the present time. It was noted that systems research methods can be supported and broadened in scope with continued attention to systems design, interface, and integration as a foundation. That work concluded that systems research

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methods must be re-developed to meet changing needs. This continues to be the perpetual case thus far.

This paper presents an analysis of systems science and engineering research as gleaned from a bibliometrics-based look at publication history and presents perspectives on the field as seen by recent leaders of the IEEE SMC Society. Section II provides contextual remarks about the systems field and current focal topics followed by a look back in time at topics covered in this journal via a bibliometric analysis and summary of thematic areas in in Section III. Finally, in Section IV, respective views of trends and future directions from SMC Society Presidents of the past decade are covered.

II. Systems Science and Engineering

Grounded in methodology for systematic problem formulation and analytical solutions regarding large and complex systems, systems engineering and systems science remain relevant to multiple industry sectors and problem domains. As systems of increased complexity continue to emerge and evolve, the challenge persists for research-driven innovations to keep pace. Fundamentally, systems are still considered to be comprised of multiple entities that could be components, subsystems, or additional systems viewed holistically through understood interrelationships and their influences on overall system behavior. The interdisciplinary field of systems science and engineering offers means to model, design, synthesize, deploy, operate, manage, study, improve and retire systems. Much of the field is concerned with the practice of systems engineering to deliver products, but it is the underlying research that sustains and advances the field, particularly when limitations in its practice are encountered.

Presently, the field is facing many challenges due in part to accelerated technology advancement and increased complexity in problems to be solved [6]. A sense for the broad topic areas drawing attention of the research community today can be gleaned from the scopes of Technical Committees focused on systems science and engineering within the IEEE SMC Society. They include autonomous and bio-inspired robotic and unmanned systems, blockchain, conflict resolution and group decision making, enterprise systems, infrastructure systems, intelligent systems, model-based systems engineering, service systems, system of systems, and system biology. Cutting across each of these research focal areas are recent advances in cybernetics-related techniques of artificial intelligence (AI), including systems science advances in dynamical systems theory, emergent behavior, and swarm engineering, not to mention methods enabling consideration of humans as integral system elements and advanced modeling and simulation.

To offer insight and appreciation of how the field has evolved to this point, the next section presents a recollection and evolution of topics published in this journal during the past 25 years.

III. Bibliometric Analysis of IEEE TSMC-S

In this section, a complete bibliometric analysis of the journal IEEE Trans. on Sys. Man & Cyb.: Systems (IEEE TSMC-S) is developed. The time window to be analyzed is 1996-2020. Then, three complementary analyses are carried out: i) a performance analysis based on bibliometric indicators, ii) the most cited articles, and iii) a science mapping of the journal to show the main research topics it has covered and its conceptual evolution.

A. Dataset

In order to retrieve the documents published by IEEE TSMC-S in the whole period, an advance query was performed in the Web of Science, taking into account the different journal names: “IEEE Transactions on Systems, Man, and Cybernetics Part A: Systems and Humans” and “IEEE Transactions on Systems, Man, and Cybernetics: Systems”. Then, a total of 3,124 documents (articles and reviews), was retrieved in October 2020.

B. Performance bibliometric analysis of IEEE TSMC-S

Firstly, a performance bibliometric analysis of IEEE TSMC-S is carried out by analyzing the evolution of the publications, their impact (received citations) across the years, and the evolution of the journal impact factor.

In Fig. 1 the distribution of publications by year, and the citations achieved are shown. As we can observe, the journal presents a growing publication pattern, publishing each year more works than in the previous one, and currently publishing three times more works than at the beginning, reaching almost 350 papers in 2020. We should point out that the year 2020 has not been fully taken into account, since the download was carried out in the last quarter of 2020.

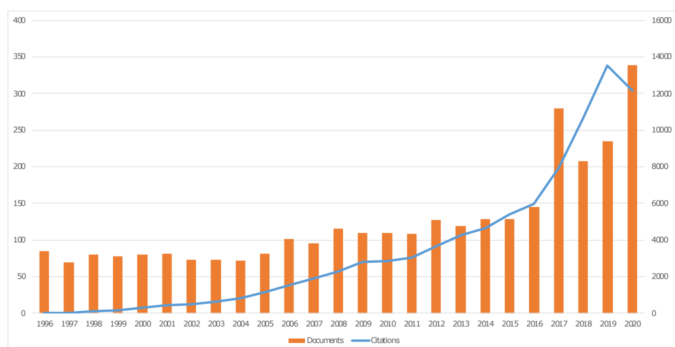

Fig. 1. Documents and citation per year.

The citations received also show a growing pattern (Fig. 1), receiving from 2018, more than one thousand citations by year.

Regarding the impact factor of IEEE TSMC-S (Clarivate’s JCR), it could be analyzed taking into account the raw measure, and also the relative position in the different categories where the journal is indexed. Fig. 2 shows the impact factor of IEEE TSMC-S published by Clarivate in the Science Citation Report, from 1997 to 2019. The changes in the impact factor have been very positive, starting in the first years below 1, and growing rapidly from 2015, reaching 9.309 in 2019.

On the other hand, using the impact factor we can analyze the relative evolution by quartiles. IEEE TSMC-S is indexed

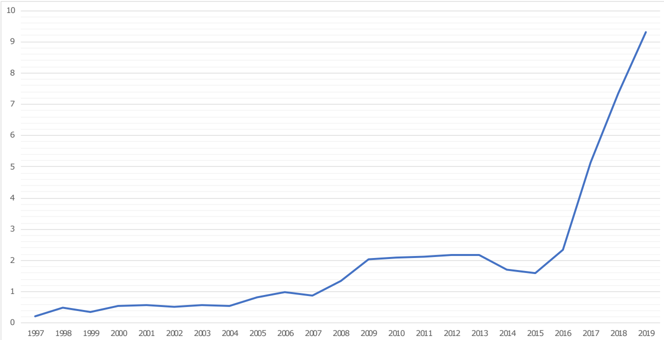

Fig. 2. Impact factor evolution.

in both WoS scientific categories, “Automation & Control Systems” and “Computer Science, Cybernetics.” The journal presents an evolutionary growth by quartiles, and currently, it is a Q1 journal in both categories.

As we can observe, the evolution of the impact factor has been a little irregular, although maintaining a positive trend. Thus, in the first years, the journal was between the third and second quartiles. In 2009, the journal managed to get into the first quartile for the first time, but it fell back into the second quartile in 2013. Finally, in 2017, the journal is once again in the top positions in both categories, and is in the top decile in the automation category in 2019. It should also be mentioned that in the early years the journal was better positioned in the automation category, but since 2007 it has reached a higher level in the computer science category.

C. Most cited articles

The previous subsection has shown the merely positive trend of the IEEE TSMC-S, in terms of both production and scientific impact. Now we analyze which papers have contributed the most to that success. That is, we will identify the most cited articles of the journal. To do that, we will use the H-Classics method [7] which is based on the application of the h-index. H-Classics states that it is possible to use h-index not only to measure the scientific performance of a scientist but also of a journal, i.e., IEEE TSMC-S. Taking into account the whole period, IEEE TSMC-S achieves an h-index of 113[1].

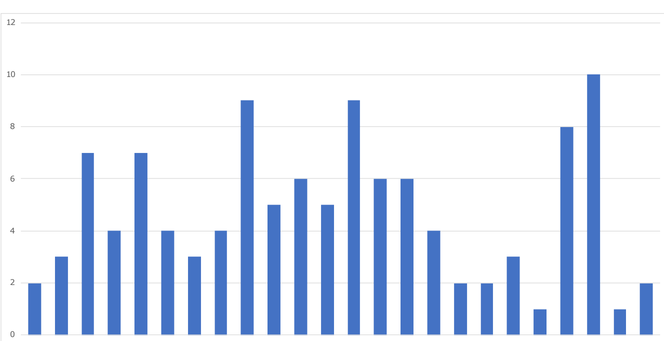

Fig. 3. Distribution of most cited paper by year.

[1]In the supplementary material, the reader could find the whole list of most cited articles

The distribution of most cited articles by year for the whole period is shown in Fig. 3. According to the citation window, an article needs between 3-7 years to achieve the majority of citations [8]. Therefore, the highly cited articles are located in the most remote years. However, IEEE TSMC-S presents highly cited articles in every single year of the whole period, reaching the peak in 2017. In fact, with the exception of some years, in each year more than 4 highly cited articles have been published. We should take into account that 2018 and 2019 are very recent to achieve the necessary impact, but even so, they have some most cited articles.

Regarding the geographic distribution of the most cited articles, Tab. I shows the countries with more than 4 most cited articles. We should mention that Peoples Republic of China and United States stand out as the countries with more most cited articles.

TABLE I
COUNTRIES WITH HIGHEST NUMBER OF MOST CITED PAPERS.

Name	Number of documents
Peoples Republic of China	49
USA	36
United Kingdom	14
Canada	10
Italy	7
France	6
Spain	4
Australia	4
Germany	4

D. Science mapping analysis of IEEE TSMC-S

In order to analyze the most important themes covered by the journal across the years, a conceptual science mapping analysis [9]–[12] based on co-words networks was carried out using SciMAT [13], [14] as the software tool. The words are the keywords of the papers published in the journal. The whole period (1996–2019) was divided into three consecutive slices: 1996–2004, 2005–2012 and 2013–2019.The separation to these specific three periods is motivated by changes in structure and names of the SMC sister Transactions. Specifically, TSMC-S started in 2013, so it was natural to break the analysis accordingly.

Then, in this section we analyze the themes covered by the journal by means of SciMAT in two different ways:

1) Showing the themes in each period and their performance measures. SciMAT provides a strategic diagram per period, where the themes discovered are classified into four categories according to two network structure measures: centrality and density. The former, measures the degree of interaction of a network with other networks. On the other hand, the density measures the internal strength of the network (we are working with network of words). Thus, the themes could be classified in the following categories:
   a) Themes in the upper-right quadrant are both well developed and important for the structuring of a

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research field. They are known as the *motor-themes* of the speciality, given that they present strong centrality and high density.

b) Themes in the upper-left quadrant have well-developed internal ties but unimportant external ties and so are of only marginal importance for the field. These themes are very *specialized and peripheral*.

c) Themes in the lower-left quadrant are both weakly developed and marginal. The themes in this quadrant have low density and low centrality and mainly represent either *emerging or disappearing* themes.

d) Themes in the lower-right quadrant are important for a research field but are not developed. This quadrant contains *transversal and general*, basic themes.

It should be mentioned that the diagrams could be enriched giving a volumen to each sphere, and for example, the volume of the spheres can be proportional to the number of documents associated with the theme.

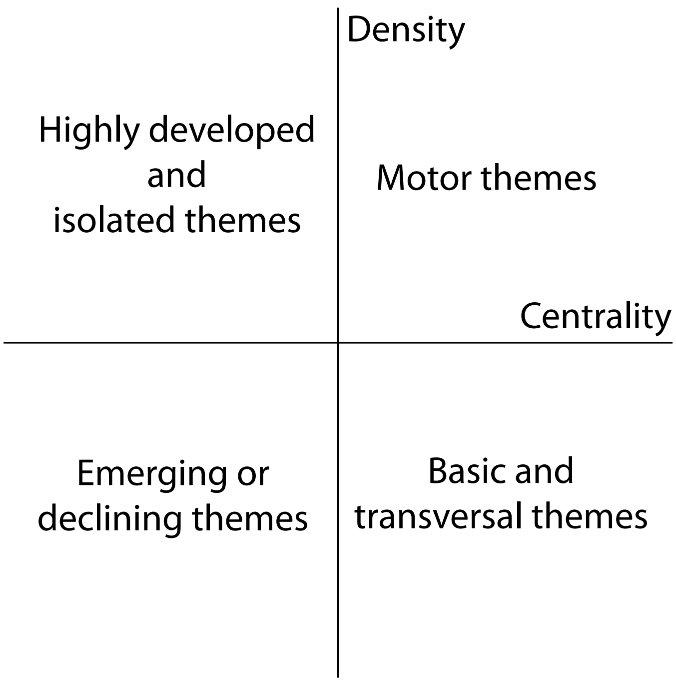

Fig. 4. The strategic diagram.

2) Determining the conceptual evolution of the themes of each period by means of detecting the thematic areas of the journal.

First period (1996–2004). According to the strategic diagram shown in Fig. 5, during this period the journal pivots on fourteen themes, with the following eight major themes (motor plus basic themes shown in both, upper-right and lower-right quadrants, respectively): *Optimization*, *Multi-attribute-decision-making*, *Human-factors*, *Computer-Vision*, *Obstacle-avoidance*, *Decision-making*, *Sliding-mode-control* and *Neural-Network*. Furthermore, the performance measures (number of documents, citations achieved and h-index) of each theme is shown in Tab. II. According to the scientific impact, five themes achieved more than one thousand citations: *Neural-Networks*, *Petri-Nets*, *Obstacle-Avoidance*, *Human-factor*, and *Multi-attribute-decision-making*.

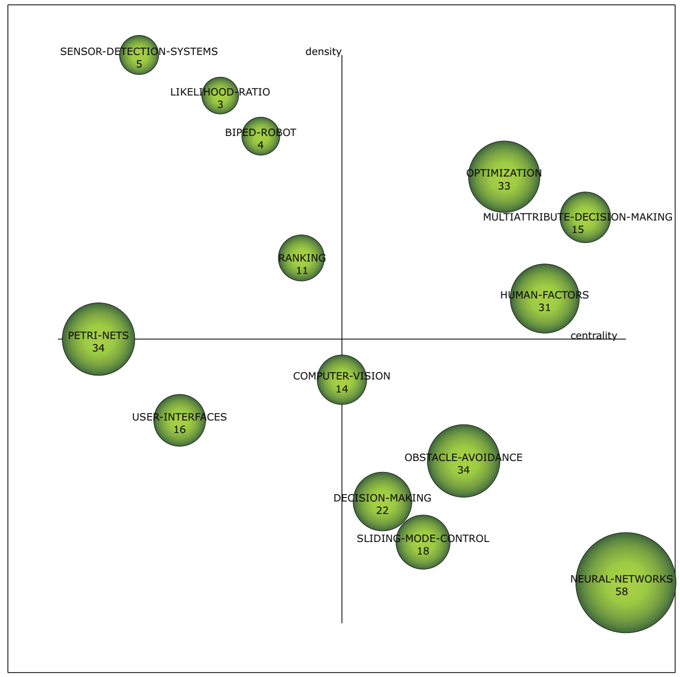

Fig. 5. Strategic diagram for the 1996–2004 period.

The theme *Neural-networks* achieved the highest impact rate (citations and h-index) and number of documents in this period. It is related with pattern, adaptive systems, dynamical systems, and also related with uncertainty systems based on fuzzy logic.

Human-factors is the second theme in terms of received citations. It is focused on the interaction between the human and computer, collaborative working, medical systems, and safety.

Petri-nets, in this period, is classified as an isolated theme, with a very low density, and medium centrality. However, this topic got a lot of citations, and as we will see in the following periods, it becomes an important theme in the journal. Mainly, it focuses on aspects related with manufacturing systems, deadlock avoidance and prevention, and discrete event systems.

Obstacle-avoidance collects the research conducted on robotics, path planning, and navigation. It presents a good impact rate and number of documents.

Multiattribute-decision-making and *Decision-making* are the beginning of an important topic in the journal. Although both themes are important in the global evolution of this topic, in this period mutliattribute-decision-making got better impact rate. Thus, it is related with evidential reasoning, and uncertainty, whereas decision-making is more focused on incomplete information and the analytic hierarchy process.

Second period (2005–2012). According to the strategic diagram shown in Fig. 6, during this period the journal delves into twenty-four themes, with the following eleven major themes (motor plus basic themes): *Warranty-cost*,

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TABLE II
PERFORMANCE OF THE THEMES IN THE 1996–2004 PERIOD.

Name	Number of documents	Number of citations	h-index
NEURAL-NETWORKS	58	2,706	27
PETRI-NETS	34	1,860	19
OBSTACLE-AVOIDANCE	34	1,570	21
OPTIMIZATION	33	863	16
HUMAN-FACTORS	31	2,288	14
DECISION-MAKING	22	841	14
SLIDING-MODE-CONTROL	18	930	11
USER-INTERFACES	16	479	12
MULTIATTRIBUTE-DECISION-MAKING	15	1,393	11
COMPUTER-VISION	14	639	10
RANKING	11	421	8
SENSOR-DETECTION-SYSTEMS	5	63	4
BIPED-ROBOT	4	375	4
LIKELIHOOD-RATIO	3	82	3

Network-reliability, *Evidential-reasoning*, *Automated-manufacturing-systems*, *Networked-control-systems*, *Linear-matrix-inequalities*, *Ranking*, *Conflict*, *Genetic-algorithm*, *Discrete-event-systems*, and *Neural-Networks*. Moreover, taking into account the performance measures shown in Tab. III, ten themes stand out achieving more than two thousand citations: *Neural-network*, *Genetic-algorithm*, *Automated-manufacturing-systems*, *Discrete-event-systems*, *Decision-making*, *Ranking*, *Classification*, *Tracking*, *Evidential-reasoning*, and *Biometrics*.

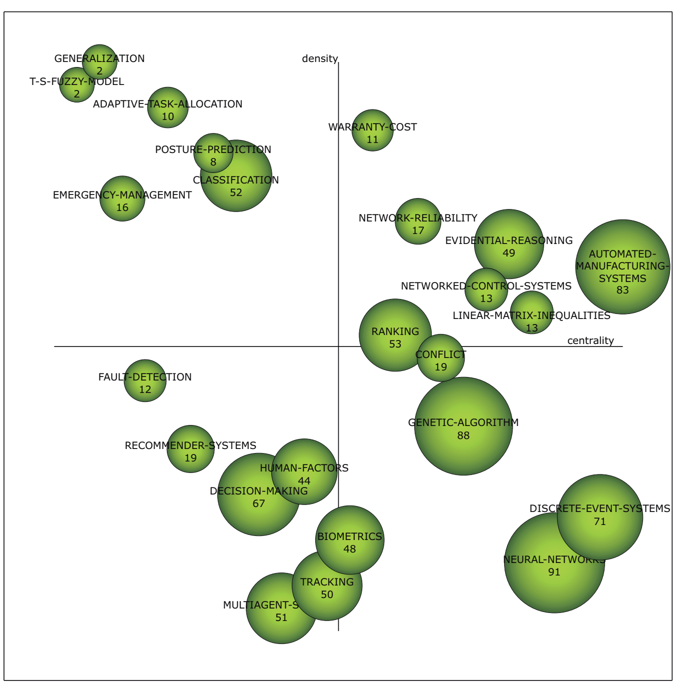

Fig. 6. Strategic diagram for the 2005–2012 period.

Automated-manufacturing-systems is the theme with highest impact rate, both in citations and h-index. It is an evolution of the theme Petri-nets of the previous period, covering topics related with allocation of resources and deadlock prevention by means of petri nets.

Neural-Networks represents the research conducted on time series and forecasting, and specific thematics such as electromyogram. It is the theme with more documents, but in terms of citations it got the second position in citations received, and the fourth in h-index.

TABLE III
PERFORMANCE OF THE THEMES IN THE 2005–2012 PERIOD.

Name	Number of documents	Number of citations	h-index
NEURAL-NETWORKS	91	3,753	29
GENETIC-ALGORITHM	88	3,578	32
AUTOMATED-MANUFACTURING-SYSTEMS	83	4,611	37
DISCRETE-EVENT-SYSTEMS	71	3,543	35
DECISION-MAKING	67	2,385	28
RANKING	53	2,105	25
CLASSIFICATION	52	2,626	24
MULTIAGENT-SYSTEMS	51	1,518	24
TRACKING	50	2,712	26
EVIDENTIAL-REASONING	49	2,290	23
BIOMETRICS	48	2,097	25
HUMAN-FACTORS	44	1,033	19
CONFLICT	19	861	15
RECOMMENDER-SYSTEMS	19	384	11
NETWORK-RELIABILITY	17	548	13
EMERGENCY-MANAGEMENT	16	617	10
LINEAR-MATRIX-INEQUALITIES	13	1,026	12
NETWORKED-CONTROL-SYSTEMS	13	694	10
FAULT-DETECTION	12	401	11
WARRANTY-COST	11	212	9
ADAPTIVE-TASK-ALLOCATION	10	289	9
POSTURE-PREDICTION	8	117	6
T-S-FUZZY-MODEL	2	63	2
GENERALIZATION	2	12	2

Discrete-event-systems is the second theme with better impact rates. It is focused on fault diagnosis, diagnosis, supervision control, etc.

Genetic-algorithm encompassed topics related with bio-inspired algorithms, such as ant colony, particle swarm, among others. Particularly, it is focused on optimization and heuristics. Regarding the performance measures, it got a really high impact rate, being the third one in citations and h-index.

Decision-making achieves more than two thousand citations, and an h-index of 28. In this period, this theme collects the research conducted on the analytic hierarchy process, combinatorial optimization, and case based reasoning.

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Ranking is another theme focused on decision making and related concepts. In that case, this theme concerns aspects connected to multi-criteria decision making, fuzzy preference relations, and also partial information. It got similar impact rates to the decision making theme.

Evidential-reasoning evolves from the theme Multi-attribute-decision-making of the previous period. It is focused on aggregation operators, uncertainty and incomplete data, decision analysis, etc.

Third period (2013–2019). According to the strategic diagram presented in Fig. 7, during this period the journal was focused on twenty-six themes, with the following thirteen major themes (motor plus basic themes): *Petri-nets*, *Multiagent-systems*, *Dynamic-surface-control*, *Adaptive-dynamic-programming*, *Analytical-models*, *Nonlinear-systems*, *Time-varying-delay*, *Robot*, *System-recovery*, *Actuators*, *Sliding-mode-control*, *Time-delay*, *Tracking*. Taking into account the performance measures, the following ten themes stand out due to their high citations (more than three thousand): *Nonlinear-systems*, *Multiagent-systems*, *Sliding-mode-control*, *Optimization*, *Dynamic-surface-control*, *Actuators*, *Adaptive-Dynamic-Programming*, *State-estimation*, *Time-delay* and *Robot*.

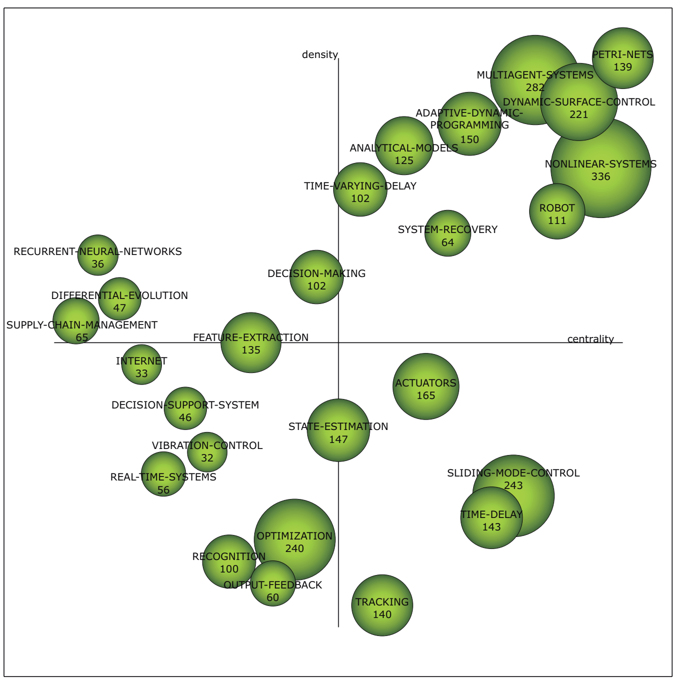

Fig. 7. Strategic diagram for the 2013–2019 period.

In this period, the theme *Nonlinear-systems* collects the research conducted on h-infinity control, stability, time delay systems, adaptive systems, and also neuronal networks. It is the theme with highest citations and h-index.

Multiagent-systems encompasses the research focused on agents and their control, such as, distributed, cooperation, topology, consensus, synchronization, protocols, etc. Taking into account the performance indicators, it is the second one with more documents, and the third one in citations achieved.

Dynamic-surface-control is related with adaptive systems,

TABLE IV
PERFORMANCE OF THE THEMES IN THE 2013–2019 PERIOD.

Name	Number of documents	Number of citations	h-index
NONLINEAR-SYSTEMS	336	10,259	55
MULTIAGENT-SYSTEMS	282	7,597	50
SLIDING-MODE-CONTROL	243	7,860	50
OPTIMIZATION	240	4,058	34
DYNAMIC-SURFACE-CONTROL	221	8,662	55
ACTUATORS	165	3,162	29
ADAPTIVE-DYNAMIC-PROGRAMMING	150	4,754	38
STATE-ESTIMATION	147	3,502	35
TIME-DELAY	143	4,131	34
TRACKING	140	2,879	32
PETRI-NETS	139	2,793	33
FEATURE-EXTRACTION	135	2,180	25
ANALYTICAL-MODELS	125	1,150	20
ROBOT	111	3,280	32
DECISION-MAKING	102	1,027	17
TIME-VARYING-DELAY	102	2,409	28
RECOGNITION	100	1,685	23
SUPPLY-CHAIN-MANAGEMENT	65	875	17
SYSTEM-RECOVERY	64	1,216	22
OUTPUT-FEEDBACK	60	1,648	24
REAL-TIME-SYSTEMS	56	1,201	18
DIFFERENTIAL-EVOLUTION	47	897	16
DECISION-SUPPORT-SYSTEM	46	658	15
RECURRENT-NEURAL-NETWORKS	36	846	15
INTERNET	33	546	12
VIBRATION-CONTROL	32	1,468	20

based on neural networks, or fuzzy systems, among others. It is the second theme with highest impact rates.

Time-delay is focuses on predictive control, stochastic systems, and others techniques able to manage time systems, and their constraints.

Petri-nets is the theme better positioned in the strategic quadrant. That is, it is the theme with best density and centrality, so it plays a central role in this period. Specifically, it encompasses the research conducted on manufacturing systems, deadlock, discrete event systems, and scheduling. On the contrary, its good structural position does not correlate with its impact rate, being placed in the middle of the ranking.

Robot deals with the techniques and problems related in the design and operation of a robot, such as, path planning, constraint, kinematics, scheduling, etc. Regarding its number of documents, it is placed in the middle of the ranking, but obtains better impact rates than themes in similar positions.

Tracking is focused on how to track different systems, such as vehicles, using cameras, containment control, or dynamical networks.

Once each period has been analyzed separately, a whole map showing the conceptual evolution of IEEE TSMC-S in the

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three consecutive periods has been carried out, identifying the main research areas considering their keywords and evolution across time. In such a way, the thematic areas that concentrate the research published in IEEE TSMC-S are: *Human factors*, *Neural networks and non-linear systems*, *Manufacturing systems*, *Bioinspired algorithms*, *Decision making*, *Intelligent control systems*, *Classification and recognition*, *Network control systems* and *Multiagent systems*.

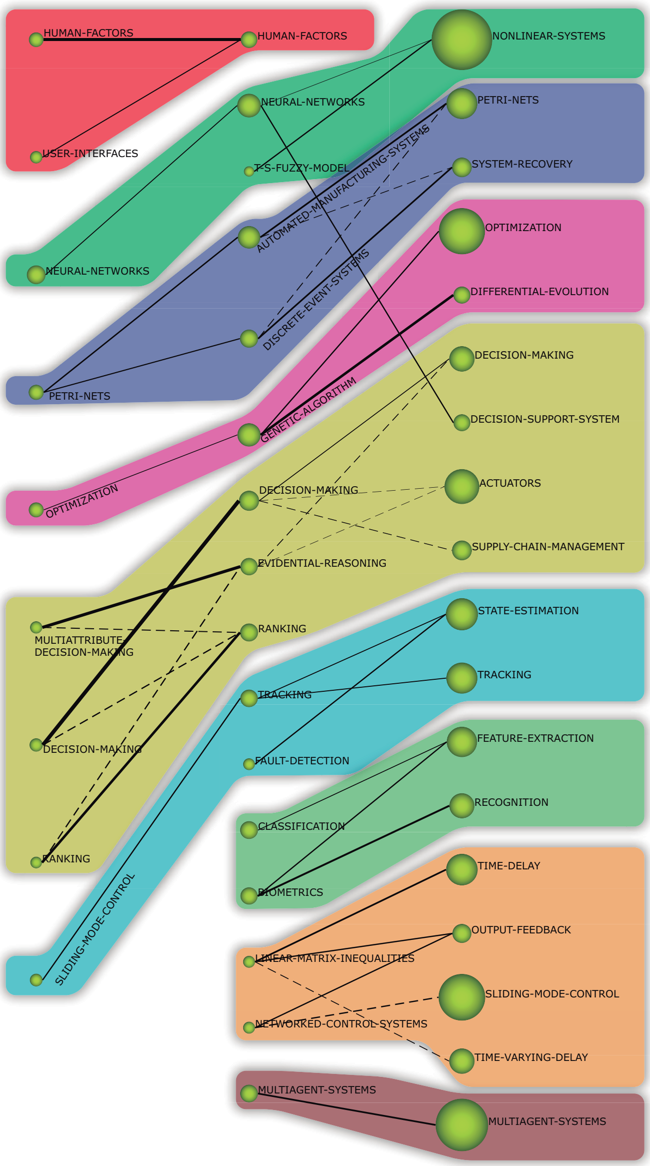

Fig. 8. Thematic evolution (1996–2019).

In Fig. 8 the conceptual evolution and the detected thematic areas are shown. In this map, a solid line implies a thematic nexus (the keyword that gives a name to one of the linked themes is inside the overlapping between both themes), whereas a dotted line means that the linked themes share a keyword not related to the central one (e.g., the keyword that gives the name to the cluster). Furthermore, the thickness of the line is proportional to the inclusion index, and the sphere volume is proportional to the number of documents associated with the theme. Finally, the different shadows represent unique thematic areas, encompassing all the themes belonging to it. As complement, in Tab. V, the performance measures for each thematic area are shown.

TABLE V
PERFORMANCE OF THE THEMATIC AREAS.

Thematic area	Number of documents	Number of citations	h-index
Human factors	79	3534	27
Neural networks and non-linear systems	484	16289	65
Manufacturing systems	323	9976	50
Bioinspired algorithms	377	8857	49
Decision making	526	12559	55
Intelligent Control systems	348	9898	53
Classification and recognition	303	7413	42
Network control systems	414	12217	60
Multiagent systems	333	9115	52

Human factors. Human involvements in control are essential, and many discussions involve attention to avoidable influence factors. Lately, researchers have respectively investigated the human factors of disassembly planning in the context of manufacturing. Some examples are based on the fuzzy attributed model to eliminate the uncertainty in disassembly behavior caused by a large amount of human intervention. More generally, increased attention has been paid to human factors in systems engineering, human-systems integration, and human-automation/-autonomy teaming. This thematic area is present in the first two periods, but in the second period, the importance of this thematic area decreases, being composed only of one declining theme (theme located in lower-left quadrant). In the third period it disappeared. Since it is the unique thematic area with no presence in the last period, it is the thematic area with less number of documents and less impact rates.

Neural networks and non-linear systems. Neural networks and fuzzy logic systems are both a kind of universal approximator. They can model complex nonlinear systems well. Many different modeling algorithms and systems are proposed. Examples are deep neural network structures and their associated designed learnings; some use a broad learning system (BLS) which is a recently proposed neural network structure. Its universal approximation property also motivates some scholars to develop new control approaches. Based on the universal approximation property, some scholars have studied the neural network/fuzzy/BLS-based control design problem for a class of complex nonlinear systems. Some works have included uncertain factors in different control problems, such as input dead zone, state constraints, input saturation, quantization, unknown control direction, etc. This thematic area presents the greatest number of documents and citation levels. Structurally, the thematic area is mainly composed of basic and isolated themes.

Automated systems. Automation is related to methods and algorithms used in automated manufacturing systems, with special focus on the use of petri nets. Petri net theory, a known area, is one of the branches of net theory, also known as special net theory. It is used particularly for simulating the dynamic nature of asynchronous concurrent systems without central control. It has been successfully used to analyze the fault-tolerant performance of operating systems and computer system structures. Structurally, this thematic area was initially composed of isolated themes (themes located in upper-left quadrant), but in the second period it consolidated and was composed of one motor and one basic theme (themes located in lower-right quadrant). Finally, in the last period this thematic area was only composed of motor themes, becoming one of the most important topics.

Optimization. This theme is one of the very important topics in this journal. Focal topics include the optimization of system designs, industrial processes, control processes, management processes, supply-chains, and life-cycles. Genetic and evolutionary-based algorithms have been used for optimization in many articles. In addition, some articles discussed differential evolution and other improvements in evolutionary-based algorithms. Structurally, the thematic area lost its importance in the journal. In the first period, it was composed of motor themes, but in the second period, the thematic area turns into basic themes, and finally it was composed only of emerging and isolated themes (themes located in lower-left quadrant).

Decision making. Decision making could be understood as the supervision and regulation activities carried out by decision makers to ensure that the implementation activities of decision makers do not deviate from the track of the decision program and the direction of the decision goal guidance. This thematic area encompasses the research conducted around the decision process, taking into account some aspects such as uncertainty, how to solve the process when multi-attributes or multi-criteria are levied upon experts, and the use of aggregation operators. Recently, researchers have utilized some statistical functions to normalize the uncertain decision matrix and built the normal model. The novel model can reflect the subjective considerations of all decision-makers and the objective information, more comprehensive information about the given objective and subjective information are obtained. It is important to highlight that this thematic area is the second largest one in terms of themes. Taking into account the performance measures, it is the second thematic area with most documents and citations.

Intelligent control systems. The development of intelligent control algorithms, the single-input-single-output model has been extended to more difficult models. These include fractional-order system, stochastic system, switching system, high order system, non-strict feedback system, pure feedback system, or time-delay in multiple-input-multiple-output form, etc. All these extensions are to satisfy the corresponding actual problems encountered and to design associated intelligent control methods. Sliding control and its extensions by combining with observer or a Hidden Markov model and event-triggered strategies are popular in the series. Relevant researches found in this thematic area are focused on robot manipulators using sliding controller, ambient intelligence by means of tracking the environment, posture classification, people counting, and vehicles and dynamical networks. It should be highlighed with not a big set of documents, this thematic area achieves a great impact rates. Regarding its structural composition, through the years, it has mainly been composed by basic themes.

Classification and recognition. This research area has focused on solving problems related to classification systems, such as imbalance class, binary classification, sampling, feature selection and extraction, advanced classified algorithms based on support vector machines or convolutional neural networks. Also, this thematic area is specially focused on developing classification systems in biometrics, which could be understood as the use of the inherent physiological characteristics and behavioral characteristics of the human body to identify individuals. Recently, based on linear logistic regression and comparing the fusion algorithms, biometric signals were proposed using several biometric devices in mismatched conditions, which allows the easy and efficient combination of matching scores from different devices and, furthermore, designs corresponding controls upon them. Structurally, this thematic area started in the second period being composed of one isolated theme and one basic theme. And in the third period, the research area was composed only of isolated themes. Thus, it is a specific thematic area in the journal.

Network control systems. This thematic area is focused on a specific intelligent control systems. In particular, it is focused on control systems applied on networks in order to solve different problems, such as, traffic problems, time delay problems, time control in networked systems, stability, packet dropout, etc. Structurally, it started in the second period with great strong, since it was composed by two motor themes. It is an important thematic area in the journal that also it stands out due to its high impact rates, being ranked second in citations, third in publications, and second in impact according to its h-index.

Multi-agent systems. Research on multi-agent systems has been very popular in recent years. It has developed rapidly since it appeared in the 1970s, and now it has become a thought method and tool for complex system analysis and simulation. The research topic of multi-agent systems can provide a suitable perspective to observe network trade, disaster response, and social structure modeling. Scholar works include leader-following consensus problem, combined with general dynamics, or under event-triggered mechanisms, or under distributed event-triggered rules. Higher-order multi-agent systems in finite time for consensus control problems with/without a leader's velocity information have been heavily discussed. Structurally, this thematic area started as an emerging theme in the second period. Later, in the third period, it consolidated as one of the main topics of the journal. Also, it achieves great bibliometric impact rates.

IV. Systems Trends and New Directions

During the past decade, the field of systems engineering and systems science has grown in demand from industry for systems engineers has grown and continues to grow. As system complexity continues to increase, so does the demand for innovative research and impactful results that enhance the tools and methods of systems engineering and systems science. Presidents of the SMC Society share a unique vantage point from which they encounter many researchers who are actively engaged in the study and advancement of the field. Such exposure combined with their individual experience and activity in the field should inform interested parties regarding significant and emerging topics. In this section, SMC Society Presidents who served terms in office spanning the past decade share their views on trends and new directions.

A. Network Science and Engineering

This section is contributed by L. Trajkovic. Since its formation as an IEEE Society in 1971, the SMC Society has been building its technical activities around the three pillars that remain the foundation of its current field of interest: Cybernetics, Human-Machine Systems, and Systems Science and Engineering [1]–[5]. The boundaries between the three technical areas have often been blurred and each area has expanded over the years to include new research directions and technological advances. Nevertheless, the three pillars still define the main interests of SMC Society members, scope of SMC publications, themes of SMC conferences, and interests of SMC Technical Committees.

The broad field of interest has enabled the SMC Society to embrace new areas, expand technical activities, and incubate other societies. We have collaborated with other IEEE Societies to support new publications and sponsor technical conferences. Most importantly, and with significant immediate impact on the society at large, prior theoretical foundations and advances in the SMC field of interest have proved instrumental in developing enabling technologies to help deal with the ongoing pandemic that is affecting all aspects of our lives. Furthermore, we are also supporting IEEE humanitarian initiatives such as the Smart Village, which gives our members opportunities to contributed to projects worldwide with a mission to transform remote communities with solar power, through education, and the creation of sustainable, affordable, locally owned, entrepreneurial energy businesses. Its vision is to bring basic electrical and educational services to millions of people by 2025.

New fields have emerged in the area of network science and engineering, and advances have been made in understanding complex systems and networks. The Internet, social networks, power grids, gene regulatory networks, neuronal systems, food webs, social systems, and networks emanating from augmented and virtual reality platforms are all examples of complex networks. One such example is the Internet with its scale-free structure, self-similar traffic, and importance of timescales in evaluating performance of its protocols and applications. Collection and analysis of data from these networks is essential for their understanding. Traffic traces collected from various deployed communication networks and the Internet have been used to characterize and model network traffic, analyze network topologies, and classify network anomalies. Data mining and statistical analysis of network data have been employed to determine traffic loads, analyze patterns of users' behavior, and predict future network traffic while spectral graph theory has been applied to analyze network topologies and capture historical trends in their development. As in other areas, machine learning has found its application in addressing cyber security and detecting network anomalies and intrusions. Recent machine learning techniques have proved valuable for predicting anomalous traffic behavior and for classifying anomalies in complex networks. Further applications of these tools will help improve our understanding of the underlying mechanisms that govern behavior, improve performance, and enhance security of social networks such as Facebook, LinkedIn, Twitter, Internet blogs, forums, and websites.

IEEE's intellectual property assets related to brain and neurotechnology has increased rapidly in the last 15 years. The SMC Society is a major player and one of the leaders in the IEEE Brain Initiative and the new IEEE Brain Technical Community. Hence, they are of strategic importance to SMC Society and will create opportunities for SMCS members to contribute to relevant publications and participate in conferences and workshops. Since 2009, the IEEE SMC Society has been organizing and supporting a Workshop on Brain-Machine Interface (BMI) Systems [15] as part of its annual flagship conferences. The Workshops have engaged a vibrant technical community that contributed to technical program sessions, delivered tutorials, engaged in interesting panel discussions and attracted prominent invited speakers. Since 2016, highlights of the Workshop programs have included Brain-Computer Interface (BCI) Hackathons.

There are a number of questions to ponder for expanding into the future: Are we expanding our field of interest in the right directions and of strategic importance to the SMC Society? Is the SMC Society still relevant to technical interests of our members? Do our conferences attract the best contributions within our wide and broad field of interest? Are our technical publications the venue of choice for publishing the most relevant and best quality research papers? Decades ago, at one of the flagship conferences, we proclaimed that "The Future is Fuzzy." It may well be that the next decade will bring the future with "The Internet of Minds."

B. The Internet of Minds

This section is contributed by M.H. Smith. We are already seeing early development of the Internet of Minds (IoM) where computing devices are neuro-controlled [16]. In the future, instead of controlling the Internet of Things (IoT) with our fingers via smartphones, we will control IoT with our minds using BCI wearables via smartphones or watches [17]. While IoT enables easy access to sensing, communications, and control across automated systems, IoM enables connected and cooperative intelligence and knowledge [18]. IoM is of particular interest to researchers and practitioners in systems science and engineering.

Our ability to read and understand brain activity is growing every day: J. Gallant has recorded brain activity while a subject viewed black-and-white photographs. His team at the University of California, Berkeley developed a computational model that enabled them to predict, with overwhelming accuracy, which picture the subject was viewing. In more recent experiments, the team has solved a much more difficult problem by

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actually decoding brain signals generated by moving pictures [19], [20].

Currently, IoM research is focusing on decoding verbal commands and motor responses directly from the brain. Such BMI devices have the potential to dramatically simplify our ability to interact with other devices such as smartphones, self-driving cars, and translation devices. Systems already exist that enable people to play video games using only EEG headsets without using fingers: Invaders Reloaded, Dagaz, BlinkSho, Awakening, FocusOasis, and Brain Driver. Nissan's Brain to Vehicle uses EEG signals to predict and detect a driver's actions and discomfort. This technology can predict an action in advance, such as a driver about to press the gas pedal or turn the steering wheel. The technology may then begin executing the action up to half a second faster than the driver [21].

Facebook plans to use optical imaging to detect one's speaking silently in their head, and then translate it into text [22]. BrainNet [23] uses EEG and transcranial magnetic stimulation (TMS) to record brain signals and deliver information noninvasively to the brain for collaborative problem solving - a "social network" of connected brains. However, while EEG does have rather low information content, there are potentially other methods that measure various kinds of signals that might be more informative. For example, Furaxa's Pico Pulse brain imager [24] uses an array of hundreds of tiny pulsed radar ICs that cover the scalp in the form of a lightweight hat and take a real-time 3D image of the shallow cortical gyri with a potential resolution of 1 mm at the rate of 1,000 frames per second. Unlike EEG and EcoG, it can provide not only lateral resolution but also spatial selectivity along the z-axis (depth).

These are all non-invasive devices. Invasive BCIs, which are implanted directly or onto the grey matter of the brain, produce the highest quality signals among BCI devices but are also more problematical. However, Neuralink has developed a new method for implanting very small brain-computer interfaces into pigs and claim to be planning human trials [25]. Nevertheless, in the near future, it is expected that non-invasive devices are the ones that are most likely to be used by most people.

For IoM to be successful, BMI wearables should have certain desirable attributes. They should be non-invasive (as we want millions to wear them) and be able to decode internal speech, dictating silent instructions to tools or silently communicate with others via their BMI wearables. They should also be able to decode covert intentions for quick response in emergencies and be very accurate and reliable. (The quality and measurement of brain activity and decoding is very important.) Furthermore, they have to be portable and low-power, safe for the brain, very unobtrusive when worn, and last a long time between charges. Eventually, we should be able to develop IoM devices that can decode information that has not yet reached the level of volitional control or conscious awareness.

However, such technological developments will lead to challenging ethical issues. For example, some will want to use advanced brain decoding in the legal realm. This is ethically fraught and would infringe on the freedom of thought. Any decoding results will have all of the limitations as eyewitness testimony. Important issues will have to be addressed such as how can we assess and ensure accuracy of brain decoding and can individuals be required to undergo brain decoding? If society uses brain decoding to make significant decisions about people's lives, and the brain decoding is wrong, this could cause serious harm to millions. Digital laws, privacy regulations, and neuro-ethics standards will have to be developed and enforced by society to avoid these issues.

If these ethical issues could be resolved, then society may greatly benefit from IoM. Two-way bi-directional communications between minds and machines would allow bypassing the limitations of our five senses, increasing the bandwidth of our brains. Humans and information technology would then be seamlessly and intuitively connected by integrating brain activity. Social media would connect everyone's thoughts via the Internet. The human brain, our memory, and our cognitive powers would be greatly enhanced. However, two-way bi-directional communications between minds and machines potentially has the risk of opening side channels to the brain. This would allow information to be uploaded to the brain without the awareness or consent of the user, fundamentally altering one's sense of agency and perception of the world: What is real and what is not?

Nevertheless, the development of IoM will depend greatly on advances in Systems Science and Engineering (SSE). In the future new world, there will be many benefits that SSE may help bring to society via IoM applications. Amputees may be able to walk and use all their limbs once again using IoM to control their prosthetics. We may all be communicating our thoughts seamlessly with each other. The ultimate social media!

C. *Evolution of Systems Thinking*

This section is contributed by D. Filev. Over the years, the flagship journal of the SMC Society – the IEEE Transactions on SMC: Systems – has evolved to a multidisciplinary professional publication promoting the synergy of general systems methodology, systems engineering technology, and model-based engineering. The diversity of topics covered by the Transactions reflects the generality of the systems idea – broad domain of exploration, interdisciplinary knowledge about the domain and wide set of methodologies for problem solving. It has grown from the original theoretical concepts of system thinking of the founding fathers – Bertalanfi, Rapoport, Boulding, Wiener and many others – to become a focal point for engineers, professionals, and researchers working in the multidisciplinary field of systems.

Going through the issues of the Transactions we can follow the evolution of the systems concept – from the broad foundation of the general systems theory through the pragmatic system engineering technology to the modern view of model-based system engineering as a generic tool for designing complex systems. Current engineering problems have expanded well beyond the traditional mechanical / electrical understanding to complex mechatronics solutions embodying software, communications, robotics, control, computers, human-machine interaction, and other engineering paradigms. Cloud and edge computing have expanded this complexity to the cyberspace. All these technologies cannot coexist without an interdisciplinary system approach.

Systems engineering has become the foundational methodology for formalizing the requirements, analyzing, validating, developing, and life cycle support of robust and structured engineering solutions. It is embedded in the practices and processes in aerospace, automotive, defense, energy, transportation, and many other industries. Over the years systems engineering has transitioned from the traditional document-/diagram-centric descriptive summaries to a model-based approach comprised by the System Modeling Language (SysML) and other standards allowing to further formalize the Product Lifecycle Management process and to link it to data analytics and simulation. Model-Based Systems Engineering technology provides opportunities for better leveraging and enacting the multidisciplinary information and knowledge, and integrating them with the other engineering tools.

AI presents another set of opportunities for disrupting systems engineering by introducing machine learning approaches to the challenging and resource consuming process of model development. AI is not a novice in the systems engineering toolbox. Numerous AI methods and tools were adopted by the systems engineering community. The first attempts at embedding knowledge in system models followed the original, cognitive wave in AI. Expert systems, hand-crafted rule-bases, case-based reasoning and ontologies were the driving force behind the knowledge-based engineering methodology for designing complex systems. The second wave of AI – neural networks, fuzzy logic and genetic algorithms – offered more opportunities for developing system models through learning rules from data and combining them with human knowledge. Nowadays, the exceptional ability of the deep machine learning methods for dealing with unstructured information – documents, speech and images – is bringing incomparable opportunities to enhance and automate the creation of system models from different information and knowledge sources using the modern tools for natural language processing and understanding. AI can further contribute to making the systems technology more adaptable, self-organizing and human friendly. On the other side, the stronger interaction between AI and the systems approach can be beneficial for transforming AI methods from a tool to an essential component of the technology stack and enterprise systems.

Celebrating the 50th anniversary of the Transactions on SMC: Systems we, the members of the broad Systems, Man, and Cybernetics community, can be proud that our publication has been and continues to be one of the main driving forces in the evolution of systems thinking as an essential factor for the progress of science and technology.

D. Transdisciplinary-SMC

This section is contributed by E. Tunstel. In its 50th anniversary year, this journal sits on a foundation solidified by a legacy of disseminating important and cutting-edge manuscripts focused on systems and associated topics on how they are modeled, engineered, analyzed and improved. It has chronicled the results and outcomes of research performed around the world, charting the advancement of the systems engineering and systems science that sustain the appetite of the research community, inform the predictions of technology forecasters, and excite technology enthusiasts. The journal will continue to be a prime mover of the IEEE SMC Society mission driving the advancement of technology enabling integration of theories towards the formulation of a general theory of systems. That mission – to promote the interdisciplinary aspects of systems science and engineering, human-machine systems, and cybernetics – is more relevant than ever as current technology trends reflect a convergence of ideas within and across these pillars of the Society's fields of interest.

Systems thinking is no longer a parochial notion among systems engineers and systems scientists but is being more widely adopted and subscribed to by many professionals across a range of sectors including technology, government, business, education and more. In order for such a broad community to benefit from systems theories and methodologies they need to be more accessible and generally applicable. This would align with a preceding trend wherein technology of ever increasing sophistication has become accessible to and applied effectively by the layperson. Enabling this for "systems" is a current and future challenge that this journal will play a part in addressing.

More increasingly, research and academic communities, along with industry, are studying and addressing problems for which synergies among a range of disciplines produce robust solutions for both individual complex systems and enterprises alike. This is impacting the development of multiple new types of systems including self-driving vehicles with associated intelligent transportation systems, emerging brain-machine interface systems, robotic and unmanned systems, smart infrastructure systems, and decision support systems. This comes with associated tools and methods that are non-traditional in the systems engineering toolbox such as the recent advances in data-driven machine learning, big data analytics, model-based approaches, and AI.

Recent advances in AI are having and will continue to have particularly broad impact on systems engineering and systems science. Theories and methodologies must adapt and keep pace to support the application of systems thinking to thinking systems. With this comes important considerations of ethical system design and social implications of AI-enabled systems, including their impact on humans at the societal level and with broader discourse from concerned fields such as law and economics. The SMC Society is sensitive to such considerations and engaged in not only the associated technological advancement but the development of relevant standards as well through sponsorship, for example, of the IEEE P7010™ standards project entitled "Wellbeing Metrics Standard for Ethical Artificial Intelligence and Autonomous Systems." That standard identifies wellbeing indicators and metrics and establishes a baseline for aligning data types that autonomous and intelligent systems should analyze and include to proactively increase human wellbeing. The indicators relate to human factors directly affected by such systems. The standard would enable developers to better consider how their products and services can increase human wellbeing based on

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a spectrum of measures beyond growth and productivity alone.

Leading research organizations focused on reporting emerging and disruptive technology trends, including but broader than AI, consistently identify technology groups of which a substantial percentage of the included technologies corresponds to focal areas of active research within the systems community that is routinely published in this journal.

Beyond the aforementioned research focal areas reflected by the scopes of SMC Society TCs, there is an emerging, overarching trend toward transdisciplinary engineering, involving the application of the individual theories and practices of multiple engineering and science disciplines. Associated transdisciplinary research will stimulate ideas for pursuit and development of systems-problem solving approaches that are agnostic to traditional boundaries across disciplines. Disparate disciplines are converging by necessity to address new systems engineering challenges [26] and greater emphasis is being placed on transdisciplinary aspects of systems science and engineering, human-machine systems, and cybernetics [27], [28].

As technologies and methodologies mature to meet new challenges, there is increasing motivation to incorporate them into real systems. This is where our knowledge of systems science and systems engineering and associated tools and methodologies are brought to bear. As our socio-technical environment is becoming more human-centric, it is more common for systems thinking to be applied to tightly integrated human-machine systems and the various cybernetics techniques enabling the current wave of AI. With more pronounced emphasis on human factors and on human relationships to technologies comprising complex systems, aspects of human modeling need to be accounted for in systems architecting, engineering, and analysis. This is reflected in the growing number of engineering problems for which models of human decision making, activity, intent, mental/thought processes, trust, and the like, are becoming integral within overall system views.

Engineered systems are also becoming more modular and architecturally open. This increases the emphasis on interoperability within and across system boundaries, raising the importance of standards and data models. This is pronounced for systems exhibiting autonomy in motion such as advanced mobile robots and unmanned and self-driving vehicles. Thinking more broadly about such mobile autonomous systems as elements of larger systems, the underlying technology is riding the same tsunami as AI, machine learning, and Internet of Things – all shaping up as elements within systems of systems. Such systems will be nodes in IoT within intelligent homes and buildings including hotels and the workplace, in logistics environments, smart factories, in intelligent highway systems, on battlefields, and more. In many applications they will be dynamic physical nodes amidst a variety of cyber-physical systems. Beyond integration of technologies, additionally considering the human element brings the question of transdisciplinary solutions into the conversation. Mobile autonomous systems with advanced AI will continually challenge the tools and methodologies being developed to engineer systems of systems in a number of ways.

As noted in [29], engineered systems with uncertainties require frequent changes as they evolve in response to varying demands; and building such systems to be reliable, sustainable, robust, with high quality and high performance requires mathematically solid systems science and engineering methodologies and system of systems thinking. This is not expected to change, as future visions for systems engineering [30] also forecast a need for "a more encompassing foundation of theory and sophisticated model-based methods and tools allowing a better understanding of increasingly complex systems and decisions in the face of uncertainty."

Considering technical areas of high relevance to its scope beyond 2020, the IEEE SMC Society?s Systems Science and Engineering Committee identified several that address foundational, engineering, and technological aspects of corresponding systems [31]. They include autonomous and adaptive systems (to deal with new demands on systems imposed by changing or evolving requirements, conditions, and environments), collaboration systems (to support human collaboration), smart systems (to handle changing or unknown environments, assist humans, or provide unanticipated system functions via self-organization), virtual/augmented/mixed reality systems (for telepresence and human augmentation), and AI systems.

Large and small companies as well as startup companies are very active in current pursuits to capture and maintain a grasp of these and other trending technologies mentioned earlier. Industry practitioners have a critical role to play in grounding such emerging technologies in practical applications and leveraging those technologies to conceive new practical solutions to industrial problems. Such industry involvement will help to address the challenge of making systems theories and methodologies more accessible and generally applicable for a broad systems thinking community.

E. Continued Roles of the IEEE SMC Society

This section is contributed by I.J. Rudas. The IEEE SMC Society is uniquely positioned as the only IEEE Society emphasizing human-centered research and development, and integrating expertise in three main areas: Systems Science and Engineering, Human-Machine Systems, and Cybernetics.

The SMC Society carries the great heritage of two of the oldest IEEE professional organizations – the "Man-Machine Systems" and "Systems Science and Cybernetics" groups that merged in the early 1970s and gave the birth to the current SMC Society. For over almost 50 years, the Society has evolved to a multidisciplinary professional organization.

Answering the rapid technology developments of the fourth Industrial Revolution (Industry 4.0), all in our three main areas, numerous TCs have been born dedicated to most of the emerging technologies; among others Brain-Inspired Cognitive Systems, Cyber-Medical Systems, Intelligent Vehicular Systems & Control, Brain-Machine Interface Systems, Blockchain, Cyber-Physical Cloud Systems, Bio-Mechatronics and Bio-Robotics Systems. The TCs form building blocks of a more effective environment; they should be complementary rather than competitive and the emphasis has to be in their synergetic collaboration.

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We should continue to be the premier reference in our areas and further grow as a driver of research and innovation, timely identifying emerging needs and opportunities.

With the extraordinary expertise and dedication that our Society offers, together we can face these challenges and enhance our profession by:

- continuing to enhance the global character of the SMC Society and gaining more benefits from international cooperation;
- making efforts to link our scientific and technical accomplishments with our educational duties;
- fostering new opportunities and enhancement of new activities for the benefit of our members and our profession.

The third decade of the 21st Century will face more challenges that will dramatically change our lives and bring new opportunities.

AI has become the main driver of emerging technologies and it will continue to act as a technological innovator for the future. To be on the frontline, we have been one of the founders of IEEE Transactions on Artificial Intelligence which is a multidisciplinary journal publishing papers on theories, methodologies and applications of AI. The spreading applications of AI could be one of the focal points of collaboration among TCs.

In Human-Machine Systems, we arrived to the dawn of spatial human-computer interaction. Interface concepts fundamentally determine all qualities of interacting with our digital devices. Since the plugs and switches of ENIAC in 1946, many revolutions have influenced the field (punched cards, CLI, GUI, mouse) taking us closer and closer to the most natural 3D environments. Various motion- and spatial-sensing technologies of the past years enabled the real-time perception of the 3D relationship between the user and the environment. As a result, most likely, Virtual, Augmented and Mixed Reality (often referred to as XR technologies) shall define the next level of Human-Computer Interaction evolution.

The machine of the 21st century is the robot, as the automobile was in the 20th century. From our point of view, great importance should be devoted to human-robot collaboration. Developing collaborative robots (cobots) that can understand their human coworkers would require further advancement in natural language understanding, processing, and generating.

A very promising new area is Cyber-Medical Systems (CMS), which integrates medical knowledge with engineering applications in order to create personalized smart healthcare techniques. Cyber-Medical Systems connect physical healthcare systems with computational components. CMS is a special class of smart systems which are related to medical devices, robotics, computer and control engineering, cloud computing, medical knowledge-based systems and of course medical science; hence, it covers basic research, applied research and industrial research issues as well.

The future of the IEEE SMC Society heavily relies on strong collaboration among the three major areas of its field of interest, through use of the most recently emerging technologies.

V. Concluding Remarks: Achievements and Aspirations

IEEE Transactions on Systems, Man, and Cybernetics: Systems has been at the forefront of pursuing advanced and innovative developments in the area of intelligent systems and their far-reaching and influential methodologies and applications, which cut across a number of the thematic areas as aforementioned. Let's brief recall how the Transactions SMC started and where it is now. This will help to identify directions of successful future development.

1971 has been the inauguration year of the new IEEE Transactions of SMC (TSMC). The predecessors of TSMC included Transactions on Systems Science and Cybernetics, and Transactions on Human Factors in Electronics, which merged into TSMC in 1971. At the end of 1971, Andrew P. Sage assumed the position of EIC which he held for 25 years. The goals of this extraordinary undertaking are clearly articulated by (Sage, 1972) in his Editorial as follows [32]:

"... Members of the [SMC] Society and vitally concerned with the methodologies which will enable man to model and control public and societal systems as well as to understand the profound effect of technological developments which affect the basic behavioral pattern of these systems. Most important perhaps is the development of the ability to discern the societal implications of technological change and desirable control strategies in order to achieve value dependent goals. Techniques of system identification may be used to devise models which, when simulated on computers, will keep track of the large number of highly interrelated variables in public and societal system problems."

These have been visionary insights, many of which were indeed accomplished in the ensuing decades, while some others are still exciting challenges for many decades ahead [33]. By 1996, TSMC expanded significantly both in its scope and volume, and it has been determined that it was time to split it into two parts.

Accordingly, Part A became "*Systems Engineering and Human Machine Systems*". It covered the formulation, analysis, modeling, decision making, and issue interpretation at any of the systems engineering life-cycle phases associated with the definition, development, and deployment of large systems. Included efforts that relate to systems management, systems engineering processes, and a variety of systems engineering methods such as optimization, modeling and simulation. It also dealt with human systems and human organizational interactions including cognitive ergonomics, system test and evaluation, and human information processing concerns in systems and organizations.

Part B "*Cybernetics*" included the field of cybernetics, or computational intelligence, including: communication and control across humans, machines and organizations at the structural or neural level as well as at functional and purposeful levels. It focused on the design and development of biologically and linguistically motivated computational paradigms emphasizing vision, neural networks, genetic algorithms, fuzzy systems, automated planning, and robotics. Also covered ap-

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plications of these concepts, in hardware and software domains [33].

Year 2013 witnessed further development of the Transactions specific goals and focus, whereas three sister Transactions were formed, Transactions of SMC-Systems, Transactions of Cybernetics, and Transactions of Human-Machine Systems. In the context of Transactions of SMC-Systems, several important trends have been identified. In the first 25 years from 1971-1996, TSMC has been an extremely productive source of cutting edge technologies, among those neural networks, fuzzy systems, and evolutionary computing are top areas. Similarly, optimization, decision making, and adaptive control methods have been excellent examples of core SMC fields. Results of many of these achievements later migrated to other research areas, and became highly beneficial technologies for the society at large, in line with the vision of our founders.

Excellent examples are the fields of neural networks and soft computing, which were incipient in Wiener's cybernetics concept, closely linking technological developments with biological, human, cognitive behaviors. TSMC has been a fertile ground of these ideas and produced many breakthrough results which shape cutting edge machine learning and artificial intelligence fields today [34]. Optimization, game theory methods, adaptive critics and dynamic programming, reinforcement learning, are key success areas emerging from TSMC. Vision has been a crucial research area from the very beginning of TSMC, producing several crucial achievements in the field. These results helped to develop advanced decision making solutions, discrete event systems, with applications in manufacturing, supply-chain management, automatization, smart grid, transportation, unmanned vehicles, robotics, manufacturing, healthcare, and many other fields.

With the emergence of fuzzy sets, new avenues have been opened and new areas established. Nowadays, they are well positioned and have enjoyed a significant level of visibility. Fuzzy sets, information granularity and granular computing have become central to a variety of real-world scenarios, and started to contribute to the analysis and synthesis of intelligent systems. They have demonstrated paramount relevance in building efficient human-centric strategies of problem solving. They are indispensable in supporting various faculties of comprehension, interpretability and explainability. The notion of partial membership advocated by Zadeh in his seminal 1965 paper established a radical and innovative departure from a binary two-way description of the world and has become an efficient conceptual vehicle to cope with the complexity and uncertainty aspects. Some pioneering papers were published in this journal, e.g., [35] which formed milestones in the advancements of the area. As examples of information granules, fuzzy sets started to play a central role in supporting knowledge representation and its processing along with coping with the complexities of systems and uncertainty factors. Further studies led to the area of Granular Computing [36], [37]. The roles of information granules and fuzzy sets have become apparent in numerous endeavors, in particular:

Systems engineering and system modeling. The principle of incompatibility coined in [35] "as the complexity of a system increases, our ability to make precise yet significant statements about its behavior diminishes... precision and significance (or relevance) become almost mutually exclusive characteristics" articulates an evident need to strike a critical balance between these two highly conflicting requirements. The adjustable levels of abstraction being realized seamlessly by information granules is instrumental in constructing manageable models, delivering modularity (through rule-based models), and generating interpretable results.

Intelligent control. Agent systems, control with linguistically defined objectives, and hierarchical control are tangible examples pointing at the role of fuzzy sets. Rule-based control has visibly positioned itself in studies on nonlinear control bringing an important aspect of domain control knowledge into the control strategies.

Decision-making models and processes. The inherent facet of uncertainty associated with complex decision processes is addressed by fuzzy sets. Their role in elicitation of knowledge, defining and building consensus, risk evaluation, and developing optimization mechanisms is indispensable.

In all these disciplines, the SMC Transactions have assumed a pioneering role to promote, disseminate innovative ideas of intelligent systems and foster synergistic studies on deploying the fundamentals and technology to solve real-world challenging problems. In the past decade, we witnessed a very exciting development when nonlinear dynamic systems theories and applications are infused into advanced control approaches. This new wave of research builds on the decades-long neural network, optimization, machine learning, computational intelligence results, producing cutting edge solutions to sliding-mode control, multi-agent control, fault-tolerant control, event-triggered control, and related areas. Our Transactions is leading force in several of these fields.

These results provide an excellent foundation to build upon. Beyond the areas mentioned earlier, there are several novel, exciting areas in which TSMC has great potential. These include cyber-physical systems, Internet-Of-Things, advanced human-computer interfaces, unmanned systems, virtual-reality, just to name a few. Nonlinear system results will enter novel computer system developments, software and hardware areas, also the ultimate integration of those in memoristive systems, and energy-efficient, edge-computing technologies. All these development are aligned with the vision of our forefathers, to develop cutting-edge technologies to support the society, the public, for the benefit of humanity.

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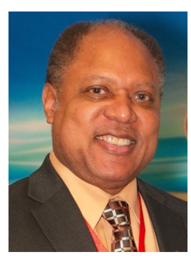

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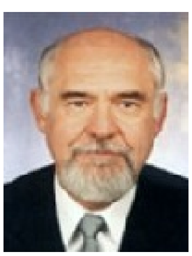

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