# SCS – 60 Years and Counting! A Time to Reflect on the Society's Scholarly Contribution to M&S from the turn of the Millennium

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**Abstract:** The *Society for Modeling and Simulation International (SCS)* is celebrating its 60th anniversary this year. Since its inception, the Society has widely disseminated the advancements in the field of Modeling & Simulation (M&S) through its peer-reviewed journals. In this paper we profile research that has been published in the journal *SIMULATION: Transactions of the Society for Modeling and Simulation International* - from the turn of the millennium to 2010; the objective is to acknowledge the contribution of the authors and their seminal research papers, their respective universities/departments, and the geographical diversity of the authors' affiliations. Yet another objective is to contribute towards the understanding of the overall evolution of the discipline of M&S; this is achieved through the classification of M&S techniques and its frequency of use, analysis of the sectors that have seen the predomination application of M&S and the context of its application. It is expected that this paper will lead to further appreciation of the contribution of the Society in influencing the growth of M&S as a discipline, and indeed, in steering its future direction.

**Keywords:** Profiling Research, Simulation Research, Simulation Practice, Author Productivity, SCS, SIMULATION: Transactions of the Society for Modeling and Simulation International

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## 1. INTRODUCTION

The *Society for Modeling and Simulation International* is a technical society that is devoted to furthering the field of Modeling and Simulation (M&S). From its inception in 1952 to the present day, the Society has effectively engaged the community it serves and has played a significant role in advancing research in simulation and allied computer arts, in applying research for solving real-world problems, in fostering networking among professionals, in organizing and sponsoring leading conferences in this area, in providing outlets for scholarly research (through Society publications), and in recognizing the achievements and contributions of both Society members and the M&S community at large [1].

As we celebrate the 60th anniversary of the Society, we believe that a fitting tribute to those "scientists and engineers, who had actively shaped and influenced the growth and development of SCS and continue to contribute to the theory, methodology, and applications of simulation science" [2] would be to present a snapshot of their scholarly contribution by undertaking a profiling study of literature that has been published in the Society's publication. So as to eliminate the ambiguity between the name of the journal and the discipline that it caters to (both being "Simulation"), the journal will henceforth be referred to in uppercase italics, i.e., as "*SIMULATION*". Although we would have liked this analysis to have encompassed the last 60 years of the history of SCS, the limited time available to us and the manual statistics compilation were the barriers that kept this analysis down to 11 years. In this study, therefore, we have considered papers that have been published from the beginning of the new millennium until 2010. Thus, the timeframe of our analyses covers a total of 11 years (2000-2010).

In the context of scholarly publications, profiling is considered to be an art of introspection [3] that aims to benefit a specific audience. Reviewing and profiling existing publications can help to identify currently under-explored research issues, and select theories and methods appropriate to their investigation, all of which are recognized in Information Systems as important issues for conducting fruitful, original and rigorous research [4, 3]. It can be argued that the same holds true for research in M&S, and indeed, most other research areas. A profiling exercise acknowledges the contributions of the authors in the development of the field (e.g., through presentation of metrics on author productivity); it identifies the geographical diversity of the author base (e.g., through presentation of metrics associated with Universities and the Departments that the authors belong to); it helps identify the major research issues and paradigms (e.g., through an analysis of keywords and future research directions); it categorizes the application areas, the research methodology, the context of its use, etc. (e.g., by reading the abstracts and the full-text); it highlights published research with the highest impact (e.g., by compiling statistics related to citation count), etc. Examples of such studies include those conducted with relation to a particular journal [5,6,3], studies that compare between journals [7, 8], or indeed those that aim to methodologically study a specific sector through a review of literature, e.g., manufacturing and business [9], healthcare [10-12] and supply chain management [13].

The aim of this paper is to profile research published in *SIMULATION: Transactions of the Society for Modeling and Simulation International* between 2000 and 2011. Towards realization of this aim the paper has the following objectives (it is to be noted that these objectives can be mapped to the eleven analyses presented in the findings section of this paper).

1. To analyze the authorship count and determine the average number of contributing authors.
2. To determine the geographical location associated with the majority of publications.
3. To determine the authors' designation.
4. To identify the institutional departments associated with the majority of publications.

5. To identify the universities and other organizations associated with the majority of publications.
6. To identify the most productive authors.
7. To identify the most-cited papers through citation analysis.
8. To determine the most commonly used M&S techniques.
9. To identify the broad areas/sectors associated with the application of M&S.
10. To identify the specific fields (within the aforementioned areas/sectors) where the application of M&S is widespread.
11. To identify topics for future research

The contribution of this profiling paper is twofold. First, it highlights the significance of the journal (and indeed the Society) in the advancement of the field of M&S. Second, it adds to the knowledge base of M&S by identifying various topics (e.g., simulation techniques and application context, future research directions) that are considered important for research and practice. The remainder of this paper is organized as follows. In the next section (Section 2) we present an overview of the journal. This is followed by a description of the methodology that was used to conduct this research (Section 3), the presentation and analysis of the findings (Section 4) and discussion and conclusion (Section 5).

## 2. OVERVIEW OF THE JOURNAL

*SIMULATION* is a peer-reviewed journal of the SCS, and has been in circulation since 1963. The journal is devoted to the publication of scholarly literature that furthers the discipline of M&S. More specifically, it encourages submissions on methodology and applications and has a strong inter-disciplinary focus [14]. Presently in its 88$^{th}$ volume, it is indexed in numerous scholarly databases (including the ISI Web of Knowledge) and has a 5-year impact factor of 0.812 [15]**.** The reputation of the journal has meant that it continues to attract a large number of submissions, which are then subjected to peer review (each submission is usually allocated three reviewers); and this constant throughput of original research and review articles have ensured that the journal has continued to offer a monthly publication frequency. The number of research papers that were published in the time span 2000-2010 varied from a minimum of 39 in 2001 to a maximum of 56 articles in 2002, with a yearly average of around 48 papers (Table 1).

*[Table 1 about here]*

Yet another indicator of the journal's reputation is the number of special issues that have been published over the years. Academics and practitioners acted as Guest Editors of Special Issues realizing the dissemination potential of the journal and its standing in the international M&S community. This is best demonstrated by the fact that the total number of special issue papers that were published between 2000-2010 was 267 - this represented approximately half of all articles published. However, as can be seen from Table 2, there is considerable variance in the number of journal issues that were devoted to these special issues. The special issue topics also demonstrate the focus of the journal on methodology and theoretical papers, as well as application-oriented papers.

*[Table 2 about here]*

## 3. LITERATURE PROFILING METHODOLOGY

The profiling exercise required the authors having to undertake an exhaustive review of papers that were published in the journal from 2000 to 2010. *SIMULATION* is the monthly publication of the Society, thus, every volume (from 2002 onwards) usually has 12 issues. The publication frequency is largely consistent during the period of analysis, the exception being the double issues that were published within this timeframe.

The papers published in the journal generally belong to one of the two categories: *regular articles* or *special issue articles*. However, between 2000 to 2004, articles were published under several other categories, including, *introduction to special issues* (total of 15 articles between 2000-2004), *columns on AI & simulation* (19 articles), *the art of modeling* (2), *the economics of modeling and simulation* (2), *advances in modeling and simulation* (7), multiple short articles under the heading – *simulation in the service of society* (21), *spotlight on M&S activities* (3), *society news and M&S news* (20) and *special issue call for papers* (21); it is to be noted that calls may appear in multiple issues). Most of the articles under these supplementary categories cannot be considered as having undergone a peer-review. Hence, in the analyses presented in this paper, we have only considered *regular articles* (258 papers) and *special issue articles* (267 papers). Thus, the total number of papers selected for the analyses is 525 (Table 1).

For every paper included in the analysis, the authors captured data on variables pertaining to the year of publication, the number of contributing authors, the author names and their affiliations (both university and department, together with their geographical location), the background of the authors (e.g., academic or practitioner), the designation of the authors, whether the paper appeared as part of a regular issue or a special issue, the simulation technique that was applied, the application domain/sector, the context of its application within a particular domain/sector, the directions for future research and the metrics on paper citations from *Google Scholar* and *ISI Web of Science*. Extracting detailed information of the aforementioned variables not only required reviewing the author information, the abstract, the conclusion (to identify future research topics) and the keywords of every paper, but in some cases it was necessary to read the full text (for example, to capture data related to the simulation techniques used, its domain/sector of application and the context of its application). Collation of data pertaining to these variables enabled the analysis of additional parameters such as the productivity of authors, institutional contributions, citations of selected articles and the geographic regions.

Data pertaining to variables such as the number of contributing authors, author names, institutional affiliations and citation count, were collated without the need for a second review, since capturing this information did not require any subjective decision making on the part of the authors. Thus, data pertaining to these variables can be recalculated and the corresponding tables (presented in Section 4) regenerated. However, for variables that required decisions to be made by the authors (e.g., the simulation techniques used, the application domain/sector and the context of its application), a peer-review approach was adopted so as to limit any bias. The rest of this section discusses information specific to the individual variables. For the benefit of the reader, we have indicated the particular sub-section (under Section 4) where the corresponding variable analysis can be found.

*Analysis based on authorship (section 4.1):* This analysis was made possible by keeping a count of the number of contributing authors in a paper.

*Analysis based on authors' geographical location (section 4.2):* The geographical location of the authors' affiliations was the underlying data used for this analysis. This analysis has taken into consideration the double affiliations reported by seven authors.

*Analysis based on authors' designation (section 4.3)*: Almost all the papers in our dataset included author biographies at the end. Using this information we were able to collate statistics on authors' background (University or Non-University) and also their designation.

*Analysis based on authors' departmental affiliation (section 4.4)*: Data pertaining to the authors' department was not always available in the articles. Moreover, for capturing data in a

readable way, we clustered departments with similar subjects and backgrounds in an attempt to minimize the number of different department names.

*Analysis based on authors' institutional affiliations (section 4.5):* The data for this analysis was readably available as almost all the papers indicated the institutional affiliation of the contributing authors. This data also allowed us to perform an analysis of institutions that are not engaged in teaching (we refer to them as "practitioner organizations"). Further, this allowed us to perform an *institutional publication* analysis by using four different measures – normal count, weighted count, adjusted count and straight count. These measures have been previously identified by [16] in the context of author productivity. The measures are described next, along with their underlying assumptions [16].

- Normal Count: We assign a weight of 1 to all the institutions associated with the co-author. The assumption here is that the contribution of every author, and thereby the institution, is equal and that more authors increase the value of the paper.
- Weighted Count: Institutions are given a reduced weight based on the number of co-authors. We follow the weighting scheme used by [17] and award 1 point to the institutions affiliated to single-author papers, 0.7 points if the paper has two authors, 0.5 points if the paper has three authors, and finally, 0.3 points if paper has four or more authors. The assumption here is that the marginal contribution of the institution is greater for research published by fewer authors.
- Adjusted Count: This is similar to weighted count, except that the weight of each article is 1 and it is divided by the total number of authors; and this is the score awarded to each institution. The assumption here is that every article is equivalent (weight of 1) and the contribution of each author, and thereby the institution, is equal.
- Straight Count: We assign a weight of 1 to only those institutions to which the first author belongs to. The assumption here is that every article is equivalent and the first author is responsible for the creation of the idea.

*Analysis based on Authors' publications (section 4.6):* The *author publication analysis* was made possible by the aggregation of papers relative to each author. Similar to the institutional productivity analysis conducted in section 4.5, we have applied four different measures in an attempt to identify the most productive authors. The four measures are normal count, weighted count, adjusted count and straight count [16]; the assumptions underlying the different measures are similar to the above.

- Normal Count: We assign a weight of 1 to all the authors associated with a particular publication.
- Weighted Count: Authors are given a reduced weight based on the number of co-authors. We follow the weighting scheme used by [17] and award 1 point for single-author papers, 0.7 points if the paper has two authors, 0.5 points if the paper has three authors, and 0.3 points if paper has four or more authors.
- Adjusted Count: The weight of each article is 1 and it is divided by the total number of authors; and this is the score awarded to each author.
- Straight Count: If there are multiple authors, only the first author is given credit for the work and receives a weight of 1.

It is to be noted here that, although the author productivity data captured will be identical to that captured for institutional productivity, however, separate measures are required to cater for a scenario wherein the author may have moved between institutions.

*Citation Analysis (section 4.7):* The citation-specific data used in these calculations were extracted from two sources — *Google Scholar* and *ISI Web of Science*.

*Analysis based on M&S technique (section 4.8):* To capture data pertaining to the M&S technique used, two authors independently and critically reviewed all papers by reading their abstracts and, if in doubt, reading the whole article. Furthermore, the authors scrutinized

papers that had coding discrepancies; the objective was to reconcile the differences pertaining to classification and to agree at a decision. Indeed, this exercise often necessitated revisiting previously classified papers for the sake of consistency. The authors then grouped the M&S technique-related data under specific headings. Since this required subjective decision making, regrettably, the tables presenting this analysis cannot be recreated. The authors also admit that the inclusion of a third reviewer could have changed the groupings to an extent; however, it is arguable that the important M&S categories identified and their corresponding frequencies would still have remained largely consistent with the present findings.

*Analysis based on M&S application areas/sectors (section 4.9):* Since this variable categorisation required subjective decision making, we adopted a peer-review methodology similar to the one used above.

*Analysis based on the context of the application of M&S in particular areas/sectors (section 4.10):* We adopted a peer-review approach similar to the one used for the analysis of the variables pertaining to *M&S technique* and *M&S application areas/sectors*. Again, the objective of this was to eliminate any unintended prejudice that could have been a result of authors' biased decision making.

*Analysis of future research directions (section 4.11):* Collection of data was made possible through the search for the keyword "future" in the full text of the papers and, additionally, by reading the concluding section of every paper (these could be sections with titles such as, summary, findings and conclusion, discussion and conclusion, future research, etc.). If the keyword was found then the associated sentence/paragraph was read so as to ascertain whether the word was used in the context of future research, and if yes, this was duly noted. Similarly, the concluding section of each of our 525 papers was read in order to identify pointers for future research. It is to be noted that a number of future research directions are direct quotes from authors; however, these have not been referenced since it was not practical to include hundreds of references in our text. Finally, the future research topics were categorized under broad headings and more specific sub-headings in order to meaningfully present the information.

The next section presents the findings of this study; however, the authors would like to voice a note of caution to the readers with regards to interpreting the data presented in this section. We emphasize that the findings of this study, in terms of most productive authors and institutions with the most contributors, should be regarded as indicative only of the journal's activity. This is because our journal-specific profiling exercise does not take into consideration several leading researchers, institutions and seminal research papers as they have not been published in this journal within the timeframe of the analysis.

## 4. FINDINGS

Our profiling exercise concluded in a series of findings. These findings are described in this section under separate headings; each heading is associated with a particular variable. More specifically, findings that relate to authors include authorship count (section 4.1), average number of authors (section 4.1), authors' designation (section 4.3) and authors' publication analysis (section 4.6); authors' affiliation-related findings include geographical locations (section 4.2), institutional departments (section 4.4) and universities (section 4.5) associated with the majority of publications; the finding that is associated with authors' publication is citation analysis (section 4.7); findings that are applicable to the discipline of M&S include, the identification and categorization of M&S techniques (section 4.8), identification of the broad areas/sectors associated with the application of M&S (section 4.9), and the context of its application (section 4.10); agenda for future research (section 4.11).

### 4.1 Analysis based on Authorship

Our analysis pertaining to the number of authors revealed that the total instances of authors that have contributed to the journal during the period 2000-2010 is 1501 (this includes seven authors who have double affiliation). The number of unique authors is 1250. Of these, 1116 (89.28%) have contributed to one paper and the remaining 134 authors have more than one contribution. Moreover, 464 (37.12%) authors appear as first authors and the remaining 786 are contributors/co-authors. Among the papers published, 13.3% were single-authored, 30.5% were by two authors, 31.2% by three authors (this forms the largest category), 14.1% by four authors, 6.3% by five authors and almost 4.6% were by six to eight authors (Table 3). In general, the average number of authors per paper was 2.84. As shown in Table 4**,** there seems to be a slight increase in the average number of authors from 2005 onwards.

*[Table 3 about here]*

*[Table 4 about here]*

### 4.2 Analysis based on Authors' Geographic Location

Our analysis of the authors' affiliations revealed that contributors came from 58 different countries, with the *US* (38.7%) clearly dominating. The second (5.6%) and the third (5.3%) largest categories were formed by authors affiliated to either *Spanish* or *Canadian* institutions respectively. *France*, *UK* and the *Netherlands* were next in the list. Table 5 shows the top 20 countries in terms of (a) the geographical location of the authors' affiliations (columns 1-3), and (b) the total region-specific contributions of the authors taking into consideration the fact that authors could have contributed to more than one paper (columns 4-6). The actual number of contributions is 1494, but 7 of the authors appear in the database with double affiliation and thus the total contributions are considered to be 1501.

*[Table 5 about here]*

It is perhaps not surprising that the largest contribution is from the *US*. This is because the journal was created and established in the US with US editors. However, the large representation of other countries indicates the journal's international audience and reputation.

### 4.3 Analysis based on Authors' Designation

This analysis considers authors' background to be in either *University* or *non-University*. Our analysis has shown that the vast majority of the authors were from the academia - 1071 authors; 85.7% compared to only 14.2% (178 authors) from the industry. This is true even though numerous papers are based on case studies (such papers generally highlight the prevalence of M&S in organizations). The predominance of authors from academia is fairly consistent throughout the period of analysis. Five authors appeared to switch between academia and practice in the period under examination, and in this case we classified the authors under the category related to most of their publications; in cases where the contributions was equal, the authors were categorized under their most recent affiliations.

Table 6 lists the top 15 author title/position. It is to be noted that 14.8% of the authors (total = 185 authors) had not indicated their title in the author biography section – this was the third largest category (excluded from percentage calculations in Table 6). Our analysis shows that the *Students* (the vast majority of whom were studying for a degree of PhD) and *Professors* were the top two author designations, each contributing to approx. 18% of publications. This was followed by *Assistant Professor* (12.9%) and *Associate Professor* (11.1%). In a number of educational systems (like in the UK), the designation of *Lecturer* and that of *Senior Lecturer* are given to academic staff working in the Universities (these can be considered equivalent to *Assistant Professor* and *Associate Professor* respectively). Thus, combining

*Assistant Professor* and *Lecturer* into a single category gives a total of 198 publications (3rd in the list – this is unchanged for *Assistant Professor*); similarly, combining *Associate Professor* and *Senior Lecturer* would mean a total of 157 publications from this joint category (4th in the list – this is unchanged for *Associate Professor*). Our analysis also shows the comparatively fewer contributions from primarily research-only staff (e.g., *Research Assistant*, *Research Fellow*, *Postdoc*).

*[Table 6 about here]*

### 4.4 Analysis based on Authors' Departmental Affiliations

Our next finding is with regard to the departments/schools in which the academic authors are located. Unfortunately for this variable we had a lot of missing data. From a total of 1250 academic authors and co-authors we could gather information for approximately 88% (1100 authors to be precise). Moreover, in order to present readable results we had to cluster the names of the authors' departments/schools under more general and distinct headings. For example, the category *Computer Science, Information & Communication Technologies (ICT) and Electronics Engineering* consists of schools and departments related to Computer Science (including, Applied CS), Computer Engineering, Computing and Mathematical Sciences, Electronics, Communications Engineering, Telecommunications, Information Sciences, M&S, etc; all the specific Engineering departments (other than those in the aforementioned category) are classified under the *Engineering* category – e.g., Aerospace Engineering, Bioengineering, Chemical and Materials Engineering, Civil Engineering, Electrical Engineering, General Engineering, Hydraulic Engineering, Industrial & Operations Engineering, Mechanical and Control Engineering and Production Engineering; *Economics & Management* category consists of Administration, Business, Economics, Econometrics, Decision Sciences, Management Science, Organizational Science, Supply Chain Management and other similar departments. In total, we formed eight such categories (shown in Table 7).

*[Table 7 about here]*

Our analysis of the department/school-specific affiliation information showed that the largest number of contributors were from departments/schools under the umbrella category of *Computer Science, Information & Communication Technologies (ICT) and Electronics Engineering* (62%). Arguably, one reason for this is, the large number of special issues that have focused on Telecommunications, Network M&S, Multiprocessor Systems and Parallel and Distributed Simulation and related areas (Table 2). This category is followed by *Engineering* (17.9%), *Economics and Management* (4.0%) and *Maths, Stats and Physics* (3.5%). Research labs have been classified under the category *Basic Sciences and Research*, and considering that this category only has a handful of research labs (e.g., IBM Austin Research, IBM T. J. Watson Research, IBM Zurich Research, Domaine Scientifique de la Doua – INSA Lyon, Google Taiwan R&D, Ford Scientific Research and C&C Research Laboratories), 2.6% of contribution is noteworthy.

### 4.5 Analysis based on Authors' Institutional Affiliations

For our next analysis we consider the affiliation information provided by the authors. Our data shows that 476 different institutions have been represented in the journal between 2000 and 2010, each institution contributing to one or more articles. 29 of the authors have changed affiliation during the years. In this case we have used either the affiliations with which they have most of their contributions or, if this is even, the most recent of their affiliations.

#### 4.5.1 Institutional Publication Analysis using Normal Count (University only)

The breakdown of the number of papers with regard to the contribution of the top 20 universities is illustrated in Table 8 (columns 1-2). Columns 3-4 show the number of unique

contributors/authors affiliated to a particular educational institution. Finally, columns 5-6 show the total number of contributions from all the authors affiliated to specific universities. Data for columns 5-6 is obtained from our database by counting the occurrence of different educational institutions associated with the authors of a paper. We call this the *total contributions approach*. This measure is different from the number of papers that each university has contributed to (columns 1-2), since there are papers with more than one author from the same institution. It is also different from the number of contributors/authors affiliated to a particular university (columns 3-4) because an author may have contributed to more than one paper. The total contributions approach results in the combined count of all authors being greater than the total number of articles.

*[Table 8 about here]*

From Table 8 we see that *Arizona State University* is ranked first with the largest number of papers (20), authors (29) and total contributions (41). *Georgia Institute of Technology* and *Amirkabir University of Technology (Iran)* rank second and third respectively with regard to unique authors and total contributions. *Georgia Institute of Technology* also features as the third largest contributor in terms of total number of papers, with the second spot being taken by *University of Arizona*. The majority of the remaining Universities that feature in the top 10 list are based in the US. The non-US Universities include, *Nanyang Technological University* and *National University of Singapore* (Singapore), *Aristotle University of Thessaloniki* (Greece), *Indian Institute of Technology (IIT) - Kharagpur* and *Indian Institute of Science (IISc) - Bangalore* (India) and *Brunel University* (UK).

### 4.5.2 Institutional Publication Analysis using Weighted Count, Adjusted Count and Straight Count (University only)

In this section we present the institutional publication analysis yet again, but using three additional measures / productivity weighting schemes, namely, normal count, weighted count and adjusted count (please refer to Section 3 on Methodology). Table 9 lists the top 20 institutions in relation to weighted count and adjusted count analysis; for straight count, the table lists only those institutions that have contributed to three or more papers as first authors. The analysis shows that, irrespective of the weighing scheme used, *Arizona State University* remains at the top, with *Georgia Institute of Technology* in second place. However, *Georgia Institute of Technology* shares the second spot with *Aristotle University of Thessaloniki (Greece)* and *Amirkabir University of Technology (Iran)* when straight count metric is used; all the three Universities have contributed 8 papers with first authors.

*[Table 9 about here]*

### 4.5.3 Analysis based on Practitioners' Organizations

There are only 161 authors who are practitioners and are represented by 113 organizations. The top four practitioner organizations, based on total contributions, are as follows: *Singapore Institute of Manufacturing Technology* (8 contributions); *Japan Agency for Marine-Earth Science and Technology* (6); *BASF Corporation* and *Ford Motor Company* (5 each); *Sandia National Laboratories* and *STMicroelectronics* (4 each). Other practitioner organizations with a total contribution of three include, *General Motors*, *Google*, *Hewlett Packard*, *IBM*, *Intel Corporation*, *MITRE Corporation*, *National Aerospace Laboratory*, *Oak Ridge National Laboratory* and *Swedish Defence Research Agency*. Finally, although the table presented in the previous section refers only to the Universities, including Non-University entities to this analysis reveals that *BASF Corporation* is ranked 5th (having five contributions with first authorship) when straight count measure is used.

### 4.6 Analysis based on Authors' Publications (Author Publication Analysis)

The focus of our next analysis was to determine the authors who have published the most number of papers during the period 2000-2010. Like section 4.5, the analysis is presented using various measures, e.g., using normal count (section 4.6.1), weighted count, adjusted count and straight count (section 4.6.2). Unlike the previous section, however, the analysis includes all the authors, irrespective of whether they are affiliated to Universities or to other organizations.

#### 4.6.1 Author Publication Analysis using Normal Count

For assessing research productivity we counted the number of publications from each author/co-author. Table 10 lists the 13 most published authors, along with their affiliations (most contributed affiliation) and geographical locations, sorted by the number of publications as well as alphabetically for authors sharing the same number of publications. In order to present the findings of this analysis, we have included only those authors in the table who have published five or more articles during the period studied. In addition to these 13 authors, our analysis shows that 15 authors contributed to 4 articles, 25 authors to 3 articles, 81 to 2 articles and, finally, the largest number of authors (1116) contributed to just the one article.

*[Table 10 about here]*

Table 10 shows that, in total, the 13 authors have contributed to 81 scholarly publications, of which they were the first authors for 26 articles. *Wainer G.A (Carleton University)* and *Chen E.J (BASF)* have the most number of publications with first authorship (5 each). Roughly half the authors in this list belong to US-based institutions; two authors are affiliated to *Nanyang Technological University* (*Turner S.J* and *Cai W*) and only one author is affiliated to a non-University entity (*Chen E.J, BASF*).

#### 4.6.2 Author Publication Analysis using Weighted Count, Adjusted Count and Straight Count

Author publication is further analysed based on normal count, weighted count and adjusted count (please refer to Section 3 on Methodology). Table 11 lists the top 10 most published authors in relation to weighted count and adjusted count; for straight count, the table lists only those authors that have three or more publications as *first author* (although this is identical to the *First Author* field in Table 10, the resultant data is dissimilar since the filters applied are different).

*[Table 11 about here]*

The table shows that *Wainer G.A* and *Chen E.J* feature prominently in our analysis, with both the authors taking up the top two positions with respect to weighted count and adjusted count respectively. *Wainer G.A* and *Chen E.J* are also tied at the top spot for straight count analysis (this has also been identified in Table 10). Futher, *Bhatnagar S*, *Boukerche A*, *Karatza H.D* and *Sadoun B* feature in all the three analyses; *Fishwick P.A*, *Giambiasi N*, *Zeigler B.P* and *Znati T* are present in two analyses.

### 4.7 Citation Analysis

We conducted a citation analysis to determine the research impact of the papers published in the journal. Citation counts can be extracted from different alternative databases such as *Google Scholar* and *ISI Web of Science*. However, recent studies have compared these databases to illustrate that both these databases possess some shortcomings which may affect the quality and the precision of citation data [18-20]. For example, [20] found that *Google*

*Scholar* records citations from all sources including conferences, book chapters, working papers, and other non-traditional sources which may affects the quality of citation data. Similarly, [18, 19] found problems in citation analysis particularly when using *ISI Web of Science* for this purpose. Since both the databases reportedly have shortcomings, we have considered it appropriate to employ both *ISI Web of Science* and *Google Scholar* for the citation analysis.

### 4.7.1 Analysis based on Total Citation

Table 12 provides citation data (only the names of the first authors are indicated) from both *Google Scholar* and *ISI Web of Science*. The articles are ranked according to the number of *Google Scholar* total citations. The table also shows the average citations (refer to section 4.7.2 for a discussion on this citation metric).

*[Table 12 about here]*

As can be seen from the table, the article by *Geem Z.W* has the highest number of total citation in both *Google Scholar* and *ISI Web of Knowledge*; the following four most-cited papers (in *Google Scholar*) also appear in the top-5 list pertaining to *ISI Web of Knowledge*, albeit in a different order. There are six papers (*Teo Y.M., Kljajic, M., Kofman E., Athanasiadis I.N., Ntaimo L. and Muzy A.*) that appear in either one of the citation databases. The papers in the most-cited list cover a breath of M&S techniques (multi-paradigm modeling, monte-carlo, discrete-event simulation, optimization, etc.) and application areas (manufacturing, distributed computing, environment, etc.). There are four papers on DEVS and several papers on agent-based simulation and systems biology.

### 4.7.2 Analysis based on Average Citation

Average citation is total citations divided by the number of years since publication. This is yet another way to measure the research impact of articles by taking into account the years passed since publication. This is important since older articles have a higher chance of having more citations, and average citations (or "citations per year") allow comparative citation measures amongst articles. Table 13 provides citation data from both *Google Scholar* and *ISI Web of Science* and ranks the articles according to the number of *Google Scholar* average citations.

*[Table 13 about here]*

As can be seen from Table 13, the paper authored by *Geem Z.W* has the highest number of average citations. This article also has the highest number of total citations in both *Google Scholar* and *ISI Web of Knowledge*. The articles by *Railsback S.F.* and *Luke S.* have the second and the third highest average citations respectively. Again, both these articles were identified among the top-five list of most-cited papers in Table 12. There are six papers that were identified in the aforementioned table, but they do not appear in Table 13 (*Wainer G.A., Teo Y.M., Kljajic, M., Mosterman P.J., Kofman E., Ntaimo L.*). The new papers that have been identified in the list of articles with the highest average citation are the papers by *Denzel W.E., Mittal S., Hamida E.B., Fassò A., Tyan H-Y. , Newport C.* and *Core M.*

## 4.8 Analysis based on M&S Technique

In this analysis we present the M&S techniques that were reported in the papers published in the journal, grouped under different categories, and report on their frequency of use. Section 3 gives more information on the methodology used to capture and group the data. We have assigned one M&S technique for each article. Articles that deal with multiple M&S techniques have been clustered either under *Multiple Techniques* (where there is equal emphasis on each technique and the techniques are applied independently) or *Hybrid Methods* (where the techniques are applied symbiotically, wherein each technique being dependent on

the other). Table 14 lists the 12 broad categories (including, "not known") and the specific M&S methods under each. The data is presented in the descending order, sorted on the number of occurrences identified for each of the 12 broad categories.

*[Table 14 about here]*

As can be seen from the table, category *Simulation Technique* has 196 occurrences; the different M&S techniques that make up this figure include, *Network M&S* (76 occurrences), *Discrete Event Simulation* (55), *Monte-Carlo* and *Numerical Simulation* (9 each), etc. Owing to the large number of papers that relate to agents (44 occurrences), we have not included this under the *Simulation Technique* category, but have created a separate category called *Agent Based Modeling and Simulation*. As has been mentioned in the methodology section, the authors had to taken subjective decision with regard to the categorization presented in this section. The other prominent categories in Table 14 include, *Parallel and Distributed Simulation* (69 occurrences), *System Modeling* with 67 occurrences (this includes Mathematical and equation-based modeling, statistical modeling, Petri nets, Markov chains, Bayesian networks, etc.), *DEVS and other Formalisms* with 37 occurrences and *Operations Research Techniques* (22 occurrences).

### 4.9 Analysis based on M&S Application Areas/Sectors

Table 15 present the areas/sectors that have seen the application of simulation techniques in the years 2000 to 2010. We have identified a total of 29 application areas (Table 15). The first position is occupied by the general area of *Methodology* and the second position is taken by the *Telecommunications sector*. The predominance of *Methodology* implies that majority of papers analyze and develop specific techniques and focus more on the method rather than on testing their application on a specific sector. *Healthcare* and *Military/Defence* have the 6$^{th}$ and the 7$^{th}$ positions with regard to the application of M&S.

*[Table 15 about here]*

### 4.10 Analysis pertaining to the Field (within an Area/Sector)

For this analysis we have applied the methodology described in Section 3 to identify the context of the application of M&S within an area/sector. We started with the 29 application areas that we identified in the previous analysis. The papers reporting on the use of M&S techniques (Section 4.8 presents this analysis) and its application area (Section 4.9 presents this analysis) also provided information on the application context (this analysis is presented here). We collated this information and this is presented in Table 16.

*[Table 16 about here]*

As can be seen from the table, the category *Methodology* was applied in several contexts, for example, framework (10 occurrences), time management – related to Parallel and Distributed Simulation (9), component-based M&S (3), etc. Similarly, M&S techniques were applied to the *Telecommunication* sector in contexts such as, analysis of networks (12 occurrences), Quality of Service (6), analysis of protocols, e.g., routing protocol, flow control, physical layer, access/admission control (numerous occurrences) and network power management (4 occurrences).

The data presented in Table 16 (and indeed the previous two tables – Tables 14 and 15) provide a reference point for discussions pertaining to the discipline of M&S. As the readers would note, the peer-review approach was adopted for capturing variable values pertaining to the M&S technique used (section 4.8), M&S application areas/sector (section 4.9) and the context of the application of M&S in particular areas/sectors (section 4.10). The objective of this was to eliminate any unintended prejudice that could have been a result of authors' biased

decision making. However, we would like the readers to be aware of certain limitations of the classification schemes that have been presented in the aforementioned tables. The limitations are discussed in the next paragraph with reference to the literature profiling methodology outlined in section 3.

As the peer-review approach was being conducted, it became evident that the majority of the discrepancies arose from the differing categorization granularity being adopted by the authors. For example, whether a paper on "agent-based distributed simulation" is codified under a new category with the same name or under an existing category (e.g., "Agent-based M&S" or "Parallel and Distributed Simulation") would be dependent on how specific the authors wanted the categorization to be (keeping in mind that the number of categories should be manageable) and, in instances where the authors independently decided against creating a new category, whether the authors felt the paper was better represented by one or the other of the available umbrella categories. In cases where there was no consensus with regard to codification, we created a new sub-category and assigned it to an overarching category with the best-fit (this was unusually achieved subsequent to reading the full-text). Taking the previous example, a sub-category called "Agent-based Distributed Simulation" was created and it was placed under the existing category of "Parallel and Distributed Simulation". In summary, the tables that we have collated have a wealth of information in them, and although we do not claim that our categorization is authoritative or objective, we believe that they can be used as a source of scholarly reference, discussion and debate.

### 4.11 Agenda for Future Research

In this final analysis we have identified a total of 313 papers that report future work (approx. 60% of the 525 papers analyzed). Of these 313 papers, a total of 238 papers (76.03%) have mentioned the keyword "future" in relation to future work (refer to section 3). The work that was reported in these papers was either general/broad-ranging (e.g., grand challenges, new research direction, inter-disciplinary research, methodological improvements applicable to a field, new tool/language development) or they were specific to work being reported by the authors (e.g., extension/enhancement to the algorithm/model presented, further implementation of research artifact, further experimentation and analysis, extending the results of the study, further investigation of issues identified in the current study, application of the proposed approach to other problems in the same domain/different domains). We identified a total of 91 papers (29.03% - out of 313) in the former category and 248 papers (79.23%) in the latter, with only 8% paper reporting on both general and specific future research. In this analysis we have included only the 91 papers that have set a broad-ranging future research agenda – these are listed in Table 17, categorized under several headings and sub-headings. The headings were selected based on their frequency and its sole purpose is to meaningfully group the identified future research topics.

*[Table 17 about here]*

One limitation of this analysis is that it uses only a single keyword "future" in the full-text search; it does not appreciate the fact that the authors may use other words like "further", "extend", "next step" to indicate the future research agenda, thereby potentially omitting these papers from further analysis. However, it can be argued that the numbers of such papers are minimal since we have also read the concluding section of the 525 papers included in our analysis, and a vast majority of papers include future research in their conclusion.

## 5. DISCUSSION AND CONCLUSION

Results from this profile are useful to the readers, the society (SCS), and the editors of *SIMULATION*. This utility derives not only from general observations about the resulting statistics, but also from questions that arise and which may need to be considered as the

journal continues to evolve. The journal remains a vibrant, and essential, forum for simulation practitioners and researchers from a wide array of countries, and for an equally wide array of topics.

Table 1 depicts a time series showing substantial peak activity in the years from 2005 to 2007, with the sole exception of 2002 where there were 55 papers. Why these hills and valleys? They may correspond with management or editorial policy changes, or they could be "noise." The special issue titles in Table 2 provides a way to gauge the relative importance placed on certain areas by editors. For example, when all of the words in Table 2 (Column 3) are analyzed by word frequency [21], as expected, words such as "systems", "simulation", and "modeling" have relatively high frequencies. The remaining top words such as "performance", "distributed", "wireless", and "network" suggest a focus on architectures and networks. This is somewhat expected since computer networks are both a domain of study for simulation, and a means to achieve faster simulations. These word frequencies also suggest that perhaps the journal needs to expand into other areas not related to performance, for diversification and broader coverage. Mean number of authors (Table 3) are not too surprising in engineering-related journals with two and three-author papers capturing over 60% of all papers. Table 5 must be carefully considered since the results are meaningful, but not normalized by country population size. For example, Singapore has just over 5 million people, whereas the United States has 307 million. Table 5 shows 484 unique authors from the U.S. and 20 from Singapore. When normalized using per capita figures, Singapore shows 4 authors per million people, and the U.S., 1.57 authors per million. One also needs to keep in mind relative densities: Singapore is highly concentrated in space with significant high technology, whereas the spatial variations differ in other countries. Table 7 shows most academic papers comes from information technology-based departments. Should other department M&S related research be targeted in future years? What about social science simulation, for example with only 1.2%? Table 15 shows some strength areas over application coverage, but also, areas for future exploration by the editors: should other areas such as education , defence, and aviation be targeted for wider coverage?

In conclusion, this paper has profiled literature published in *SIMULATION: Transactions of the Society for Modeling and Simulation International* - from the turn of the millennium to 2010. As the *Society for Modeling and Simulation International (SCS)* celebrates its 60$^{th}$ anniversary this year, it is important to acknowledge the scholarly contribution of the Society in the development of the field of M&S. It is with this objective that we have presented analyses on institutions (e.g., those associated with the majority of publications), authors (e.g., authors with the most publications) and articles (e.g., total citations and average citations). Further, this paper has presented findings on M&S application areas, M&S techniques and M&S application contexts, and it is expected that this will further add to our understanding of the evolution of this field of M&S. Finally, through this exercise we have attempted to review and reflect on the development of the journal during the period of our analysis.

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## TABLES

**Table 1: Total number of papers published (2000-2010)**

| Year | #Papers |
|---|---|
| 2000 | 44 |
| 2001 | 39 |
| 2002 | 55 |
| 2003 | 48 |
| 2004 | 48 |
| 2005 | 54 |
| 2006 | 55 |
| 2007 | 51 |
| 2008 | 44 |
| 2009 | 45 |
| 2010 | 42 |
| **Total** | **525** |

**Table 2: Special issues and the total number of papers in each issue (2000-2010)**

| Year | Issue | Title of Special Issue | # Papers |
|---|---|---|---|
| 2000 | July-August | Mobile and Wireless Communications and Information Processing | 5 |
| | Nov-Dec | Simulation in the Automotive Industry | 4 |
| 2001 | April | Simulation in Education and Education in Simulation | 5 |
| | June | Software Agents and Simulation | 4 |
| | September | Simulation and Visualization | 5 |
| | November | M&S Applications in Scheduling Multiprocessor Systems | 6 |
| 2002 | March-April | ATM Systems and Networks: Basics, Issues and Performance Modeling and Simulation | 12 |
| | May | Supply Chain Management | 5 |
| | July | Simulation and Modeling of Computer Systems and Networks | 6 |
| 2003 | March | Modeling and Analysis of Semiconductor Manufacturing | 6 |
| | May | Simulation of Systems and Protocols for Wired and Wireless Environments | 6 |
| | December | Systems Biology and Simulation | 6 |
| 2004 | January | Air Transportation | 4 |
| | March | Simulation Methodologies for Logistics and Manufacturing Optimization | 6 |
| | May | Modeling and Simulation Applications in Cluster and Grid Computing | 6 |
| | July-August | Component-Based M&S | 6 |
| | September | Grand Challenges for M&S | 4 |
| | December | Military Simulation Systems and Command and Control Systems Interoperability | 4 |
| 2005 | January | Applications of Parallel and Distributed Simulation in Industry | 7 |
| | February | Applications of DEVS Formalisms | 5 |
| | March | Agent-Based Simulation Modeling in Social and Organizational Domains | 4 |
| | April | Parallel and Distributed Simulation | 7 |
| | June | M&S of Emerging Wireless and Sensor Network Technologies and Applications | 4 |
| | July | Agent-directed Simulation | 4 |
| | August | Performance Evaluation of Wireless Systems | 5 |
| | September | Manufacturing and Logistics Systems Performance | 5 |
| 2006 | January | Best of PADS 2005 | 5 |
| | February | Recent Advances in Network M&S | 3 |
| | May | Internet and Wireless Network Performance | 5 |
| | June | Recent Advances in M&S of Network Systems | 4 |
| | July | Ecological and Environmental Simulation | 5 |
| | November | M&S in Teaching and Training | 8 |
| 2007 | January | Service-Orientated Computing Paradigm | 7 |
| | February | Advances in Performance Evaluation of Computer and Telecommunication Systems | 5 |
| | March | New Challenges in Large-Scale Computer Systems and Network M&S | 6 |
| | April | Performance M&S in Healthcare Information Systems | 4 |
| | May | Air Transportation | 4 |
| | July | High Performance Computing in Simulation | 6 |
| | December | Rare Event Simulation: Methodologies and Applications | 8 |
| 2008 | February | Performance Evaluation of Computer and Telecommunication Systems | 7 |
| | May | Distributed Simulation, Virtual Environments and Real Time Applications | 5 |

| | | | |
|---|---|---|---|
| | October | Principles of Advanced and Distributed Simulation | 6 |
| 2009 | February | M&S of Power Electronic Systems | 3 |
| | April | Principles of Advanced and Distributed Simulation | 4 |
| | August | Performance Evaluation of Computer and Telecommunication Systems | 4 |
| | September | Advanced and Distributed Simulation | 4 |
| | November | Multi-paradigm Modeling | 6 |
| 2010 | January | Recent Advances in Unified Modeling and Simulation Approaches | 4 |
| | May/June | Software Tools, Techniques and Architectures for Computer Simulation | 6 |
| | August | Healthcare Simulation: Potentials and Challenges | 7 |
| **Total** | | | **267** |

**Table 3: Authorship count**

| Number of Contributing Authors | Count | Percent |
|---|---|---|
| 1 | 70 | 13,3% |
| 2 | 160 | 30,5% |
| 3 | 164 | 31,2% |
| 4 | 74 | 14,1% |
| 5 | 33 | 6,3% |
| 6 | 18 | 3,4% |
| 7 | 5 | 1,0% |
| 8 | 1 | 0,2% |
| **Total Papers** | **525** | **100,0%** |

**Table 4: Average number of authors (2000-2010)**

| Year | Mean #Authors | Standard Deviation | #Papers |
|---|---|---|---|
| 2000 | 2,7 | 1,4 | 44 |
| 2001 | 2,5 | 1,1 | 39 |
| 2002 | 2,5 | 1,2 | 55 |
| 2003 | 2,7 | 1,3 | 48 |
| 2004 | 2,6 | 1,5 | 48 |
| 2005 | 3,1 | 1,3 | 54 |
| 2006 | 3,1 | 1,6 | 55 |
| 2007 | 2,9 | 1,2 | 51 |
| 2008 | 3,1 | 1,4 | 44 |
| 2009 | 2,9 | 1,1 | 45 |
| 2010 | 3,1 | 1,1 | 42 |
| **Total** | | | **525** |

**Table 5: List of the top 20 geographical locations based on (a) authors' affiliation (b) and total number of author contributions**

| Country (a) | Unique Authors (a) | Total % (a) | Country (b) | Author Contributions (b) | Total % (b) |
|---|---|---|---|---|---|
| US | 484 | 38,7% | US | 581 | 38,7% |
| Spain | 70 | 5,6% | Spain | 78 | 5,2% |
| Canada | 66 | 5,3% | Canada | 76 | 5,1% |
| France | 57 | 4,6% | France | 65 | 4,3% |
| UK | 52 | 4,2% | UK | 62 | 4,1% |
| Netherlands | 50 | 4,0% | Netherlands | 59 | 3,9% |
| China; Germany | 47 *each* | 3,8% *each* | Germany | 51 | 3,4% |
| Italy | 44 | 3,5% | China | 50 | 3,3% |
| South Korea | 33 | 2,6% | Italy | 48 | 3,2% |
| Greece | 26 | 2,1% | South Korea | 47 | 3,1% |
| Taiwan | 25 | 2,0% | Singapore | 44 | 2,9% |
| India | 24 | 1,9% | India | 40 | 2,7% |
| Korea; Singapore | 20 *each* | 1,6% *each* | Greece | 35 | 2,3% |
| Turkey | 17 | 1,4% | Taiwan | 34 | 2,3% |
| Iran | 16 | 1,3% | Iran | 23 | 1,5% |
| Australia; Brazil | 13 *each* | 1,0% *each* | Korea | 21 | 1,4% |
| Sweden | 12 | 1,0% | Turkey | 18 | 1,2% |
| Hungary | 9 | 0.7% | Sweden | 15 | 1,0% |
| New Zealand | 8 | 0.6% | Brazil | 14 | 0,9% |
| Slovenia | 7 | 0.6% | Australia | 13 | 0,9% |

**Table 6: List of top 15 author designations**

| Author Designation | Total | Total % |
|---|---|---|
| Student | 222 | 17,8% |
| Professor | 221 | 17,7% |
| Assistant Professor | 161 | 12,9% |
| Associate Professor | 139 | 11,1% |
| Research Associate | 46 | 3,7% |
| Lecturer | 37 | 3,0% |
| Research Assistant | 36 | 2,9% |
| Software Engineer | 32 | 2,6% |
| Senior Lecturer | 18 | 1,4% |
| Research Fellow | 17 | 1,4% |
| Director | 15 | 1,2% |
| Senior Scientist | 7 | 0,6% |
| Researcher;<br>Expert Advisor/Counsellor/Consultant | 6 *each* | 0,5% *each* |
| Emeritus Professor;<br>Postdoc;<br>Research Engineer;<br>Senior Engineer;<br>Technical Staff | 5 *each* | 0,4% *each* |
| Project Manager | 4 | 0,3% |

**Table 7: Classification of the authors' departmental affiliation under eight broad categories**

| Academic Departments | Total | Total % |
|---|---|---|
| Computer Science, Information & Communication Technologies (ICT) and Electronics Engineering | 682 | 62,0% |
| Engineering (Mechanical, Civil, Electrical, etc.) | 197 | 17,9% |
| Economics and Management | 44 | 4,0% |
| Maths, Stats and Physics | 39 | 3,5% |
| Basic Sciences and Research | 29 | 2,6% |
| Medical-Health | 21 | 1,9% |
| Social Sciences | 13 | 1,2% |
| Others | 75 | 6,8% |
| **TOTAL** | **1100** | **100,0%** |

**Table 8: List of the top 10 institutions based on Simple Count: (a) Total Papers – columns 1 and 2, (b) Unique Authors – columns 2 and 4, (c) Total Contribution – columns 5 and 6.**

| Institution and #Total Papers | | Institution and #Unique Authors | | Institution and #Total Contribution | |
|---|---|---|---|---|---|
| Arizona State University | 20 | Arizona State University | 29 | Arizona State University | 41 |
| University of Arizona | 14 | Georgia Institute of Technology | 26 | Georgia Institute of Technology | 34 |
| Georgia Institute of Technology | 13 | Amirkabir University of Technology | 19 | Amirkabir University of Technology | 26 |
| Aristotle University of Thessaloniki | 10 *each* | University of Illinois at Urbana-Champaign | 15 | Nanyang Technological University | 24 |
| Carleton University; Monmouth University; Nanyang Technological University; University of Illinois at Urbana-Champaign; University of Pittsburgh | 9 *each* | University of Pittsburgh | 13 | University of Illinois at Urbana-Champaign | 22 |
| Amirkabir University of Technology; Indian Institute of Technology, Kharagpur | 8 *each* | Aristotle University of Thessaloniki; George Mason University | 12 *each* | University of Arizona | 21 |
| Korea Advanced Institute of Science and Technology; Texas A&M University; University of Amsterdam; University of Florida | 7 *each* | University of Amsterdam | 11 | Aristotle University of Thessaloniki; University of Pittsburgh | 19 *each* |
| University of Cincinnati; University Polytechnic of Catalunya | 6 *each* | Nanyang Technological University; University of Ottawa | 10 *each* | Indian Institute of Technology, Kharagpur | 15 |
| Brunel University; National Chiao Tung University; National University of Singapore; Purdue University; University of Central Florida | 5 *each* | Budapest University of Technology and Economics; Carnegie Mellon University; Huazhong University of Science and Technology; University of Cantabria; University of Twente; Virginia Polytechnic Institute and State University | 9 *each* | Carleton University; National Chiao Tung University; University of Amsterdam | 14 *each* |
| Auburn University; George Mason University; Harbin Institute of Technology; Indian Institute of Science; Paul Cézanne University; University Autonomous of Barcelona; University of Aix-Marseille; University of Twente; Virginia Polytechnic Institute and State University; Vrije University Amsterdam | 4 *each* | Auburn University; National Chiao Tung University; Purdue University; University of Arizona; University of Central Florida; University of Florida; University of Ljubljana; University of Southern California; University Polytechnic of Catalunya | 8 *each* | University of Florida | 13 |

**Table 9: List of the top institutions based on (a) Weighted Count – columns 1 and 2, (b) Adjusted Count – columns 3 and 4, and (c) Straight Count– columns 5 and 6.**

| Institution (Wgt. Count=Top 20) | Weighted Count | Institution (Adj. Count=Top 20) | Adjusted Count | Institution (Straight Count >= 3) | Straight Count |
|---|---|---|---|---|---|
| Arizona State University | 19.30 | Arizona State University | 13.37 | Arizona State University | 13 |
| Georgia Institute of Technology | 14.20 | Georgia Institute of Technology | 9.27 | Georgia Institute of Technology; Aristotle University of Thessaloniki; Amirkabir University of Technology | 8 *each* |
| Amirkabir University of Technology | 11.20 | Aristotle University of Thessaloniki | 7.98 | Carleton University | 7 |
| Aristotle University of Thessaloniki | 10.80 | Amirkabir University of Technology | 7.97 | University of Pittsburgh; University of Illinois at Urbana-Champaign; Nanyang Technological University | 6 *each* |
| University of Arizona | 10.20 | University of Arizona | 7.64 | University of Florida; Purdue University | 5 *each* |
| University of Illinois at Urbana-Champaign; Nanyang Technological University | 9.00 *each* | University of Pittsburgh | 6.57 | University of Arizona; University of Central Florida; Texas A&M University; Korea Advanced Institute of Science and Technology; Brunel University; University of Amsterdam; Vrije University Amsterdam | 4 *each* |
| Carleton University | 8.90 | Carleton University | 6.52 | | |
| University of Pittsburgh | 8.60 | Nanyang Technological University | 6.14 | | |
| University of Florida | 7.50 | University of Illinois at Urbana-Champaign | 6.04 | | |
| Korea Advanced Institute of Science and Technology | 6.80 | University of Florida | 5.79 | | |
| Indian Institute of Technology, Kharagpur | 6.50 | Korea Advanced Institute of Science and Technology | 4.73 | University of North Texas; Harbin Institute of Technology; New Jersey Institute of Technology; University of Illinois at Chicago; National University of Singapore; Florida State University; University Nacional of Rosario; Budapest University of Technology and Economics; University of Cincinnati; Al-Balqa' Applied University; Indian Institute of Science; George Mason University; University Autonomous of Barcelona; Linköping University; Auburn University; University of Warwick; Inha University; National Chiao Tung University; Indian Institute of Technology, Kharagpur; Huazhong University of Science and Technology; University of Ottawa; | 3 *each* |
| University of Amsterdam | 6.40 | Indian Institute of Technology, Kharagpur | 4.64 | | |
| University of Cincinnati | 6.30 | University of Cincinnati | 4.50 | | |
| Monmouth University; National Chiao Tung University | 5.00 *each* | University of Amsterdam | 4.41 | | |
| | | Monmouth University | 3.57 | | |
| National University of Singapore | 4.80 | National Chiao Tung University | 3.38 | | |
| Budapest University of Technology and Economics | 4.50 | National University of Singapore | 3.36 | | |
| George Mason University; University of Ottawa | 4.40 *each* | George Mason University | 3.25 | | |
| Harbin Institute of Technology; University of Aix-Marseille | 4.30 *each* | Al-Balqa' Applied University | 3.00 | | |
| University of Central Florida | 4.20 *each* | Harbin Institute of Technology; University of Aix-Marseille; University of Ottawa | 2.99 *each* | | |

**Table 10: List of the top 13 most published authors with five or more publications, their affiliations and the order of authorship**

| Author | Institution | Country | Total papers | First author | Co-author |
|---|---|---|---|---|---|
| Obaidat M.S | Monmouth University | US | 9 | 2 | 7 |
| Zeigler B.P | University of Arizona | US | 9 | 0 | 9 |
| Wainer G.A | Carleton University | Canada | 8 | 5 | 3 |
| Turner S.J | Nanyang Technological University | Singapore | 7 | 0 | 7 |
| Giambiasi N | University of Aix-Marseille | France | 6 | 0 | 6 |
| Karatza H.D | Aristotle University of Thessaloniki | Greece | 6 | 3 | 3 |
| Znati T | University of Pittsburgh | US | 6 | 2 | 4 |
| Cai W | Nanyang Technological University | Singapore | 5 | 0 | 5 |
| Chen E.J | BASF Corporation | US | 5 | 5 | 0 |
| Chen Y | Arizona State University | US | 5 | 3 | 2 |
| Hu X | Georgia State University | US | 5 | 1 | 4 |
| Mukherjee A | Indian Institute of Technology, Kharagpur | India | 5 | 2 | 3 |
| Vahidi B | Amirkabir University of Technology | Iran | 5 | 3 | 2 |

**Table 11: List of the top published authors based on (a) Weighted Count – columns 1 and 2, (b) Adjusted Count – columns 3 and 4, and (c) Straight Count – columns 5 and 6.**

| Author (Wgt. Count=Top 10) | Weighted Count | Author (Adj. Count=Top 20) | Adjusted Count | Author (Straight Count >= 3) | Straight Count |
|---|---|---|---|---|---|
| Wainer G.A | 5.30 | Chen E.J | 4.50 | Chen E.J;<br>Wainer G.A | 5 *each* |
| Chen E.J | 4.70 | Wainer G.A | 4.03 | Boukerche A | 4 |
| Karatza H.D | 4.50 | Karatza H.D | 3.50 | Bhatnagar S;<br>Bosse T;<br>Chen Y;<br>Huang C-Y;<br>Karatza H.D;<br>Lee J.S;<br>Lee J-K;<br>Rao D.M;<br>Sadoun B;<br>Vahidi B | 3 *each* |
| Obaidat M.S;<br>Zeigler B.P | 4.30 *each* | Obaidat M.S | 3.07 | | |
| Znati T | 3.70 | Fishwick P.A;<br>Sadoun B;<br>Znati T | 3.00 *each* | | |
| Fishwick P.A;<br>Giambiasi N | 3.40 *each* | Zeigler B.P | 2.98 | | |
| Sadoun B | 3.00 | Giambiasi N | 2.41 | | |
| Bhatnagar S | 2.80 | Kofman E | 2.33 | | |
| Boukerche A | 2.70 | Boukerche A | 2.16 | | |
| Kim T.G | 2.60 | Barros F.J;<br>Bhatnagar S;<br>Gustafsson L;<br>Hofmann M.A;<br>Raczynski S | 2.00 *each* | | |

**Table 12: List of the top 15 most-cited papers (*Google Scholar* and *ISI Web of Science*)**

| Article (only the first author is indicated) | Google Scholar (sorted based on Total Cites) | | ISI Web of Science (#ranked) | |
|---|---|---|---|---|
| | Total Citations | Average Citations | Total Citations | Average Citations |
| **Geem Z.W.** (2001). A New Heuristic Optimization Algorithm: Harmony Search, *76: 60-68.* | 440 | 44,0 | 209 (#1) | 20,9 |
| **Railsback S.F.** (2006) Agent-based Simulation Platforms: Review and Development Recommendations, *82: 609-623.* | 186 | 37,2 | 60 (#3) | 12,0 |
| **Luke S.** (2005). MASON: A Multiagent Simulation Environment, *81: 517-527.* | 172 | 28,7 | 49 (#5) | 8,2 |
| **Cuellar A.A.** (2003). An Overview of CellML 1.1, a Biological Model Description Language, *79: 740-747.* | 104 | 13,0 | 57 (#4) | 7,1 |
| **Cho K-H.** (2003). Experimental Design in Systems Biology, Based on Parameter Sensitivity Analysis Using a Monte Carlo Method: A Case Study for the TNFα-Mediated NF-κB Signal Transduction Pathway, *79: 726-739.* | 85 | 10,6 | 62 (#2) | 7,8 |
| **Fowler J.W.** (2004). Grand Challenges in Modeling and Simulation of Complex Manufacturing Systems, *80: 469-476.* | 72 | 10,3 | 24 (#9) | 3,4 |
| **Wainer G.A.** (2001). Application of the Cell-DEVS Paradigm for Cell Spaces Modeling and Simulation, *76: 22-39.* | 72 | 7,2 | 21 (#10) | 2,1 |
| **Lakoba T.I.** (2005). Modifications of the Helbing-Molnár-Farkas-Vicsek Social Force Model for Pedestrian Evolution, *81: 339-352.* | 69 | 11,5 | 30 (#7) | 5,0 |
| **Faller D.** (2003). Simulation Methods for Optimal Experimental Design in Systems Biology, *79: 717-725.* | 62 | 7,8 | 36 (#6) | 4,5 |
| **Teo Y.M.** (2001). Comparison of Load Balancing Strategies on Cluster-based Web Servers, *77: 185-195.* | 58 | 5,8 | | |
| **Cournède P-H.** (2006). Structural Factorization of Plants to Compute Their Functional and Architectural Growth, *82: 427-438.* | 53 | 10,6 | 25 (#8) | 5,0 |
| **Kljajic, M.** (2000). Simulation Approach to Decision Assessment in Enterprises, *75: 199-210.* | 50 | 4,5 | | |
| **Mosterman P.J.** (2004). Computer Automated Multi-Paradigm Modeling: An Introduction, *80: 433-450.* | 48 | 6,9 | 16 (#12) | 2,3 |
| **Kofman E.** (2002). A Second-Order Approximation for DEVS Simulation of Continuous Systems, *78: 76-89.* | 47 | 5,2 | | |
| **Hu X.** (2005). Variable Structure in DEVS Component-Based Modeling and Simulation, *81: 91-102.* | 43 | 7,2 | 16 (#12) | 2,7 |
| **Athanasiadis I.N.** (2005). A Hybrid Agent-Based Model for Estimating Residential Water Demand, *81: 175-187.* | | | 21 (#10) | 3,5 |
| **Ntaimo L.** (2004). Forest Fire Spread and Suppression in DEVS, *80: 479-500.* | | | 17 (#11) | 2,4 |
| **Muzy A.** (2005). Specification of Discrete Event Models for Fire Spreading, *81: 103-117.* | | | 16 (#12) | 2,7 |

**Table 13: List of the top 15 papers with the highest average citation count (Google Scholar and ISI Web of Science)**

| Article (only the first author is indicated) | Google Scholar (sorted based on Avg. Cites) | | ISI Web of Science (#ranked) | |
|---|---|---|---|---|
| | Average Citations | Total Citations | Average Citations | Total Citations |
| **Geem Z.W.** (2001). A New Heuristic Optimization Algorithm: Harmony Search, *76: 60-68.* | 44,0 | 440 | 20,9 (#1) | 209 |
| **Railsback S.F.** (2006). Agent-based Simulation Platforms: Review and Development Recommendations, *82: 609-623.* | 37,2 | 186 | 12,0 (#2) | 60 |
| **Luke S.** (2005). MASON: A Multiagent Simulation Environment, *81: 517-527.* | 28,7 | 172 | 8,2 (#3) | 49 |
| **Denzel W.E.** (2010). A Framework for End-to-End Simulation of High-performance Computing Systems, *86: 331-350.* | 15,0 | 15 | | |
| **Cuellar A.A.** (2003). An Overview of CellML 1.1, a Biological Model Description Language, *79: 740-747.* | 13,0 | 104 | 7,1 (#5) | 57 |
| **Mittal S.** (2009). DEVS/SOA: A Cross-Platform Framework for Net-centric Modeling and Simulation in DEVS Unified, *85: 419-450.* | 12,0 | 24 | | |
| **Lakoba T.I.** (2005). Modifications of the Helbing-Molnár-Farkas-Vicsek Social Force Model for Pedestrian Evolution, *81: 339-352.* | 11,5 | 69 | 5,0 (#6) | 30 |
| **Cho K-H.** (2003). Experimental Design in Systems Biology, Based on Parameter Sensitivity Analysis Using a Monte Carlo Method: A Case Study for the TNFα-Mediated NF-κB Signal Transduction Pathway, *79: 726-739.* | 10,6 | 85 | 7,8 (#4) | 62 |
| **Cournède P-H.** (2006). Structural Factorization of Plants to Compute Their Functional and Architectural Growth, *82: 427-438.* | 10,6 | 53 | 5,0 (#6) | 25 |
| **Hamida E.B.** (2009). Impact of the Physical Layer Modeling on the Accuracy and Scalability of Wireless Network Simulation, *85: 574-588.* | 10,5 | 21 | | |
| **Fowler J.W.** (2004). Grand Challenges in Modeling and Simulation of Complex Manufacturing Systems, *80: 469-476.* | 10,3 | 72 | 3,4 (#9) | 24 |
| **Fassò A.** (2010). A Unified Statistical Approach for Simulation, Modeling, Analysis and Mapping of Environmental Data, *86: 139-153.* | 10,0 | 10 | | |
| **Tyan H-Y.** (2009). Design, Realization and Evaluation of a Component-based, Compositional Network Simulation, 85: 159-181. | 9,0 | 18 | 2,5 (#12) | 5 |
| **Newport C.** (2007). Experimental Evaluation of Wireless Simulation Assumptions, 83: 643-661. | 8,8 | 35 | 2,8 (#10) | 11 |
| **Core M.** (2006). Teaching Negotiation Skills through Practice and Reflection with Virtual Humans, 82: 685-701. | 8,2 | 41 | | |
| **Faller D.** (2003). Simulation Methods for Optimal Experimental Design in Systems Biology, 79: 717-725. | | | 4,5 (#7) | 36 |
| **Athanasiadis I.N.** (2005). A Hybrid Agent-Based Model for Estimating Residential Water Demand, 81: 175-187. | | | 3,5 (#8) | 21 |
| **Hu X.** (2005). Variable Structure in DEVS Component-Based Modeling and Simulation, 81: 91-102. | | | 2,7 (#11) | 16 |
| **Muzy A.** (2005). Specification of Discrete Event Models for Fire Spreading, 81: 103-117. | | | 2,7 (#11) | 16 |

**Table 14: M&S Techniques**

| | | |
|---|---|---|
| **A. Simulation Techniques** | | **196** |
| | NETWORK MODELING AND SIMULATION | 76 |
| | DISCRETE EVENT SIMULATION | 55 |
| | MONTE CARLO SIMULATION; NUMERICAL SIMULATION | 9 *each* |
| | FINITE ELEMENT METHOD-BASED MODELING AND SIMULATION; REAL TIME SIMULATION | 7 *each* |
| | DISCRETE-EVENT SIMULATION AND VISUALIZATION; SYSTEM DYNAMICS; TRACE-BASED SIMULATION | 4 *each* |
| | CONTINUOUS SIMULATION/FLOW SIMULATION; STATISTICAL SIMULATION (INCLUDING REGRESSION AND POISSON SIMULATION) | 3 *each* |
| | RARE EVENTS SIMULATION; SOFTWARE-IN-THE-LOOP SIMULATION; STOCHASTIC SIMULATION; VIRTUAL REALITY SIMULATION; WEB-BASED SIMULATION | 2 *each* |
| | CHAOS-BASED SIMULATION; INTERVAL-BASED MICROSCOPIC SIMULATION; QUALITATIVE SIMULATION AND PREDICTION; SIMULATION VISUALIZATION; SPREADSHEET SIMULATION | 1*each* |
| | | |
| **B. Parallel and Distributed Simulation** | | **69** |
| | PARALLEL AND DISTRIBUTED SIMULATION | 32 |
| | DISTRIBUTED SIMULATION | 22 |
| | AGENT-BASED DISTRIBUTED SIMULATION | 6 |
| | PARALLEL SIMULATION | 4 |
| | DISTRIBUTED INTERACTIVE SIMULATION | 3 |
| | GRID-BASED SIMULATION; WEB-BASED DISTRIBUTED SIMULATION | 1*each* |
| | | |
| **C. Systems Modeling** | | **67** |
| | MATHEMATICAL AND EQUATION-BASED MODELING | 25 |
| | BOND GRAPH MODELING; PETRI NETS | 9 *each* |
| | MARKOV-CHAIN MODELING | 6 |
| | MULTI-PARADIGM MODELING | 4 |
| | STATISTICAL MODELING; STOCHASTIC MODELING | 3 *each* |
| | VISUAL INTERACTIVE MODELING | 2 |
| | BAYESIAN NETWORKS; DISCRETE-TIME MODELING; GERT -GRAPHICAL EVALUATION AND REVIEW TECHNIQUE; META-MODELING; MODEL VERIFICATION AND VALIDATION; SEMI-MARKOV MODEL | 1 *each* |
| | | |
| **D. Agent Based Modeling and Simulation** | | **44** |
| | AGENT-BASED MODELING AND SIMULATION | 34 |
| | MULTI-AGENT SYSTEMS | 9 |
| | AGENT-BASED GEO-SIMULATION | 1 |
| | | |
| **E. Discrete Event System Specification (DEVS) and other Formalisms** | | **37** |
| | DEVS | 26 |
| | DEVS - CELL-DEVS | 2 |
| | COMPOSABLE CELLULAR AUTOMATA FORMALISM; DEVS – DEVS/SOA; DEVS – DSDEV; DEVS – EUDEVS; DEVS – GDEVS; DEVS – RTDEVS; DEVS - CELL SPACE APPROACH (NOTE: THIS IS DIFFERENT FROM CELL-DEVS); FORMAL SPECIFICATION AND ANALYSIS (MAUDE); HETEROGENEOUS FLOW SYSTEM SPECIFICATION FORMALISM | 1 *each* |
| | | |
| **F. Application-Specific Modeling and Simulation** | | **31** |
| | ANALYSIS OF ALGORITHMS (INCLUDING SIMULATION OF ALGORITHM) | 8 |

| | | |
|---|---|---|
| | PHYSICS-BASED MODELING AND SIMULATION (INCLUDING N-BODY AND VOXEL-BASED SIMULATION) | 3 |
| | BIOLOGICAL PATHWAY MODELING; LOGIC SIMULATION; SOUND SIMULATION | 2 |
| | ARCHITECTURE SIMULATION; CHEMICAL SIMULATION; CIRCUIT SIMULATION; COMPUTERIZED TOMOGRAPHY SIMULATION; CONSTRUCTIVE MILITARY SIMULATIONS; DRIFT PATH SIMULATION; EMBEDDED SIMULATION; ENGINEERING SIMULATION; JOB SHOP SIMULATION; LANDSLIDE SIMULATION; LOAD FLOW MODELING; SIMULATION AND GAMING; SIMULATION OF FLIGHT MECHANICS; THERMODYNAMIC SIMULATION | 1*each* |
| | | |
| **G. Programming/Specification Languages/Frameworks/Methodology** | | **24** |
| | OBJECT ORIENTED SIMULATION | 6 |
| | PROGRAMMING (INCLUDING, FUZZY LINEAR PROGRAMMING, GENETIC PROGRAMMING, INTEGER PROGRAMMING, INTEGER LINEAR PROGRAMMING) | 4 |
| | COMPONENT-BASED MODELING AND SIMULATION | 2 |
| | ARCHITECTURE DESCRIPTION LANGUAGES; CELLULAR AUTOMATA PROGRAMMING ENVIRONMENT; DATA EXCHANGE MODEL; EXTENSIBLE BATTLE MANAGEMENT LANGUAGE; FINITE STATE MACHINES MODELING LANGUAGE; FORMAL CO-DESIGN FRAMEWORK; GESAS II METHODOLOGY; OBJECT-ORIENTED MODELING LANGUAGE; PARALLEL OBJECT-ORIENTED SPECIFICATION LANGUAGE; PROGRAMMING ENVIRONMENT FOR SIMULATOR; PROGRAMMING LANGUAGE; SERVICE-ORIENTED ARCHITECTURE (SOA) SIMULATION | 1*each* |
| | | |
| **H. Operations Research Techniques (including Optimization and AI-based approaches)** | | **22** |
| | OPTIMIZATION (INCLUDING GENETIC ALGORITHM OPTIMIZATION, METAHEURISTIC-BASED OPTIMIZATION, PARTICLE SWAN OPTIMIZATION, SIMULATION-BASED OPTIMIZATION) | 10 |
| | ARTIFICAL INTELLIGENCE (INCLUDING FUZZY INDUCTIVE REASONING AND NEURAL NETWORKS) | 6 |
| | HEURISTICS | 3 |
| | MULTIOBJECTIVE DECISION ANALYSIS; SCHEDULING; UNCERTAINTY MODELING | 1*each* |
| | | |
| **I. Multiple Techniques** | | **13** |
| | VARIOUS | 7 |
| | (DISCRETE-EVENT SIMULATION + HARDWARE-IN-THE-LOOP SIMULATION); (GENETIC ALGORITHM-BASED OPTIMISATION + FINITE-ELEMENT METHOD + GRID-ENABLED PARALLEL SIMULATION); (KINEMATIC VEHICLE MODELING + VR MODELING); (MONTE-CARLO SIMULATION + PETRI NET MODELING); (POLICY SPECIFICATION LANGUAGE + POLICY DEVELOPMENT FRAMEWORK + DISTRIBUTED SIMULATION); (VERY HIGH SPEED INTEGRATED CIRCUITS HARDWARE DESCRIPTION LANGUAGE [VHDL] + ARTIFICIAL NEURAL NETWORK + FUZZY LOGIC) | 1*each* |
| | | |
| **J. Hybrid Methods** | | **8** |
| | INTELLIGENT AGENTS WITH QUEUING NETWORK MODEL; MESOSCOPIC SIMULATION (MICROSCOPIC AND MACROSCOPIC SIMULATION) | 2 *each* |
| | DISCRETE-CONTINUOUS COMBINED SIMULATION; HYBRID SYMBOLIC-NUMERICAL SIMULATION METHOD; HYBRID SYSTEM EXAMPLES; MONTE CARLO–BASED DISCRETE EVENT SIMULATION | 1 *each* |
| | | |
| **K. Not known** | | **8** |
| | | |
| **L. Uncategorised** | | **6** |
| | KNOWLEDGE-BASED SYSTEMS AND EXPERT SYSTEMS | 3 |
| | MODEL-BASED INFORMATION-PROCESSING SYSTEMS; PERFORMANCE EVALUATION OF SIMULATED SYSTEMS; RELIABILITY SIMULATION | 1 *each* |
| **TOTAL** | | **525** |

**Table 15: Application areas/sectors**

| Application Areas / Sectors | Count | Percentage (%) |
|---|---|---|
| Methodology | 112 | 21,29% |
| Telecommunications | 98 | 18,82% |
| Engineering | 50 | 9,51% |
| Distributed Computing | 40 | 7,60% |
| Manufacturing | 30 | 5,70% |
| Health care | 26 | 4,94% |
| Military/Defence | 23 | 4,37% |
| Computers | 19 | 3,61% |
| Environment | 18 | 3,42% |
| Air Transport | 13 | 2,47% |
| Automotive; Education | 12 *each* | 2,28% *each* |
| Road Transport; Urban studies | 11 *each* | 2,09% *each* |
| Systems Biology | 9 | 1,71% |
| Marine / Water Transport | 6 | 1,14% |
| Logistics; Supply chain | 5 *each* | 0,95% *each* |
| Rail Transport | 4 | 0,76% |
| Astronomy; Construction; Mobile Computing; Retailing and Wholesaling; Space | 3 *each* | 0,57% *each* |
| Mining / Metals | 2 | 0,38% |
| E-Business; Economics; Public Administration; Sports | 1 *each* | 0,19% *each* |
| **TOTAL** | **525** | **100%** |

**Table 16: Analysis pertaining to context of application (within an Area/Sector)**

| | | |
|---|---|---|
| **A. Methodology** | | **112** |
| | SIMULATION ENVIRONMENT / PLATFORM / LANGUAGE | 13 |
| | FRAMEWORK | 10 |
| | TIME MANAGEMENT | 9 |
| | RARE EVENT SIMULATION | 6 |
| | HYBRID M&S | 5 |
| | PERFORMANCE EVALUATION; VERIFICATION & VALIDATION | 4 *each* |
| | COMPLEX SYSTEMS; COMPONENT-BASED M&S; OPTIMIZATION ALGORITHM; SIMULATION EXPERIMENTATION / EXPERIMENTATION DESIGN; SIMULATION OUTPUT ANALYSIS; VR MODELING / VIRTUAL ENVIRONMENTS | 3 *each* |
| | COLLABORATIVE SIMULATION ENVIRONMENT / TOOL; DATA DISTRIBUTION MANAGEMENT; HYBRID SYSTEMS; MODEL INTEGRATION / MODEL COMPOSIBILITY; POISSON SIMULATION / POISSON PROCESS; REAL TIME SYSTEMS; VISUALIZATION | 2 *each* |
| | ARTIFICIAL INTELLIGENCE; AUTOMATIC MODEL COMPLETION; BUSINESS PROCESS SIMULATION; CHAOS-BASED SIMULATION; CONSTRUCTION OF MODELS; CONTINUOUS SYSTEMS; DERIVATIVE ESTIMATION; EVENT LIST; FAULT TOLERANCE; GRAPHICAL MODELS; GRID-BASED SIMULATION; INPUT DATA ANALYSIS; LARGE-SCALE SIMULATION; MODEL EXTRACTION; MODEL SELECTION; MODEL TRANSFORMATION; NETWORK TRAFFIC; PROPORTION ESTIMATION; QUANTIZATION-BASED SIMULATION; QUEUING SYSTEMS; SIMULATION CLONING; SIMULATION INTEROPERABILITY; SIMULATION MODEL REUSE; SIMULATION PRACTICE; STATE MANAGEMENT; TIME-PARALLEL SIMULATION; TIME-SERIES FORECASTING; TRAINING SIMULATOR; UNCERTAINTY MODELING | 1 *each* |
| | | |
| **B. Telecommunications** | | **98** |
| | ANALYSIS OF NETWORKS | 12 |
| | NETWORK SECURITY; PROGRAMMING/NETWORK SIMULATION ENVIRONMENT; PROTOCOL M&S (ROUTING) | 8 *each* |
| | DESIGN OF INTEGRATED ARCHITECTURES | 7 |
| | NETWORK QOS | 5 |
| | MULTIMEDIA SERVICES; POWER MANAGEMENT; PROTOCOL M&S (CONGESTION CONTROL) | 4 *each* |
| | PROTOCOL M&S (FLOW CONTROL) | 3 |
| | DISTRIBUTED NETWORK SIMULATION/PARALLEL NETWORK SIMULATION; OPTIMAL CONFIGURATION OF NETWORKS; PROTOCOL M&S (ACCESS/ADMISSION CONTROL); PROTOCOL M&S (COMMUNICATION); PROTOCOL M&S (PHYSICAL LAYER); PROTOCOL M&S (SCHEDULING); REUSABILITY; SCALABILITY OF NETWORKS; SPEED OF SIMULATION EXECUTION | 2 *each* |
| | EMPIRICAL MODELS; END-USER STUDIES; EXECUTION TIME; INTELLIGENT NETWORKS; LOAD BALANCING; NETWORK EMULATION; NETWORK MANAGEMENT; NETWORK MOBILITY; NETWORK RECONFIGURATION; PRICING; PROTOCOL M&S (DEADLOCK RECOVERY); PROTOCOL M&S (TDMA); PROTOCOL M&S (ACCESS/ADMISSION CONTROL); PROTOCOL M&S (WIRELESS); REVIEW; VOICE QUALITY; WORKLOAD MODELING | 1 *each* |
| | | |
| **C. Engineering** | | **50** |
| | POWER SYSTEM DESIGN / POWER TRANSMISSION | 12 |
| | M&S OF PHYSICAL SYSTEMS | 8 |
| | DESIGN OF SYSTEMS; FAULT DIAGNOSIS / FAULT DETECTION AND ISOLATION | 6 *each* |
| | MOVEMENT OF FLUIDS / FLOW SIMULATION | 4 |
| | CONTROL SYSTEMS / FACTORY AUTOMATION SYSTEMS / EXPERT SYSTEMS | 3 |
| | M&S OF PHYSICAL PROCESSES; MODELING FRAMEWORK; TRAINING SIMULATOR | 2 *each* |
| | AUDIO SIGNAL PROCESSING; FLOOD MANAGEMENT; LOGIC SIMULATION; MODEL DRIVEN ENGINEERING; REVIEW | 1 *each* |

| | | |
|---|---|---|
| | | |
| **D. Distributed Computing** | | **40** |
| | SCHEDULING; WWW / SOA / WEB SERVICES | 8 *each* |
| | DESIGN OF DISTRIBUTED SYSTEMS | 5 |
| | LOAD BALANCING/RESOURCE MANAGEMENT | 4 |
| | COMMUNICATION; EXECUTION/PROGRAMMING ENVIRONMENT; SIMULATION OF HPC SYSTEMS | 3 *each* |
| | DATA REPLICATION; P2P NETWORKS; PEER-TO-PEER (P2P) GAMING; SCALABILITY; TRANSACTION MANAGEMENT; VIRTUAL ENVIRONMENTS | 1 *each* |
| | | |
| **E. Manufacturing** | | **30** |
| | FACTORY / PRODUCTION LINE / JOB SHOP SIMULATION; SIMULATION OF PHYSICAL SYSTEMS / PROCESS | 6 *each* |
| | FAULT DIAGNOSIS / FAULT DETECTION AND ISOLATION | 4 |
| | WEB-BASED SIMULATION | 2 |
| | COMPLEX MANUFACTURING SYSTEMS; EXECUTION SPEED; ENTERPRISE DECISION-MAKING SUPPORT; GRID-BASED SIMULATION; INVENTORY MANAGEMENT; LEAN MANUFACTURING; QUALITY IMPROVEMENT; REPAIR AND MAINTENANCE; SHOP-FLOOR CONTROL SYSTEMS; SIMULATION INTEROPERABILITY; SIMULATION-BASED ORDER ACCEPTANCE; SYSTEM RECONFIGURATION | 1 *each* |
| | | |
| **F. Healthcare** | | **26** |
| | EPIDEMIC M&S; MODELING OF PHYSICAL SYSTEMS / COMPUTED TOMOGRAPHY | 4 *each* |
| | HOSPITAL / CLINIC MANAGEMENT; SCHEDULING | 3 *each* |
| | HEALTHCARE INFORMATICS; OPERATING THEATRES; REVIEW | 2 *each* |
| | A&E; LEAN / JIT; SIMULATION OF DISORDERS; SUPPLY CHAIN SIMULATION; TRAINING; VIEWPOINT | 1 *each* |
| | | |
| **G. Military / Defence** | | **23** |
| | SIMULATION INTEROPERABILITY; TRAINING | 4 *each* |
| | MILITARY COMMUNICATIONS | 3 |
| | BEHAVIOUR REPRESENTATION | 2 |
| | AIRBORNE OPERATIONS; AVAILABILITY OF WEAPON PLATFORMS; CASUALTY EVACUATIONS; DYNAMIC BEHAVIOUR OF SIMULATION; EMBEDDED SIMULATION; LIVE–VIRTUAL–CONSTRUCTIVE (LVC) SIMULATION; MISSILE THREAT SIMULATION; RADAR INTERFERENCE; SIMULATION STATE UPDATES; SYSTEM DECOMPOSITION | 1 *each* |
| | | |
| **H. Computers** | | **19** |
| | COMPUTER ARCHITECTURE | 6 |
| | MICROPROCESSOR ARCHITECTURE | 5 |
| | EMULATION; EXECUTION/PROGRAMMING ENVIRONMENT; FORMAL DESIGN METHODS; GPU; HUMAN-COMPUTER INTERFACE; REAL TIME COMPUTERS; SOFTWARE ARCHITECTURE; UBIQUITOUS COMPUTING | 1 *each* |
| | | |
| **I. Environment** | | **18** |
| | ECOLOGY MODELING | 7 |
| | SPREAD OF FIRE | 4 |
| | MODELING FOREST LANDSCAPES | 3 |
| | METHODOLOGY FOR ENVIRONMENT MODELING; TERRAIN MODELING / LANDSLIDE MODELING | 2 *each* |
| | | |
| **J. Air Transport** | | **13** |

| | | |
|---|---|---|
| | AVIATION SAFETY | 4 |
| | AIR AND GROUND TRAFFIC CONTROL; AIR NETWORK SIMULATION; EVOLUTION OF THE AIRLINE INDUSTRY; FLIGHT CONTROL SYSTEM; FUTURE OF AIR TRANSPORTATION; M&S INFRASTRUCTURE FOR AIRPORTS; RISK MANAGEMENT; TRAINING; VISUALISATION OF AIRPORT OPERATIONS | 1 *each* |
| | | |
| **K. Automotive** | | **12** |
| | DESIGN OF AUTOMOBILES | 5 |
| | AUTOMOBILE PRODUCTION LINE | 4 |
| | AUTOMOBILE SAFETY; DRIVING SIMULATOR; SOUND MODELING | 1 *each* |
| | | |
| **L. Education** | | **12** |
| | SIMULATION PEDAGOGY; SIMULATION-BASED TRAINING AND TEACHING | 4 *each* |
| | VISUAL INTERACTIVE AND MULTIMEDIA SIMULATIONS | 3 |
| | DESIGN OF SIMULATION COURSE | 1 |
| | | |
| **M. Road Transport** | | **11** |
| | TRAFFIC LIGHT CONTROL / TRAFFIC SIGNAL TIMINGS | 3 |
| | INTELLIGENT TRANSPORTATION SYSTEM | 2 |
| | DRIVING BEHAVIOUR; HYBRID MODELING; INCIDENT MANAGEMENT; OPERATION OF A TOLL PLAZA; SURFACE TRANSPORTATION SYSTEM; TRAINING SIMULATOR | 1 *each* |
| | | |
| **N. Urban studies** | | **11** |
| | BEHAVIOURAL M&S; WATER MANAGEMENT | 4 *each* |
| | CROWD M&S | 2 |
| | ORGANISATIONAL ADAPTION | 1 |
| | | |
| **O. Systems Biology** | | **9** |
| | BIOLOGICAL MODELING | 3 |
| | EXPERIMENTAL DESIGN; MODELING ENVIRONMENT / MODELING DESCRIPTION LANGUAGE | 2 *each* |
| | FUNCTIONAL GENOMICS; MODEL DECOMPOSITION | 1 |
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| **P. Marine / Water Transport** | | **6** |
| | ANALYSIS OF PHYSICAL SYSTEMS; CONTROL SYSTEMS; DESIGN OF SYSTEMS; INVESTMENT DECISIONS; MARITIME TRANSPORT SYSTEM; TRAINING SIMULATOR | 1 *each* |
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| **Q. Logistics** | | **5** |
| | OPTIMIZATION | 3 |
| | PLANNING; QUALITY IMPROVEMENT | 1 *each* |
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| **R. Supply chain** | | **5** |
| | DISTRIBUTED SUPPLY CHAIN SIMULATION | 3 |
| | HYBRID SUPPLY CHAIN SIMULATION; SUPPLY CHAIN SIMULATION | 1 *each* |
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| **S. Rail Transport** | | **4** |
| | CONTROL SYSTEMS; INTERMODAL TRANSPORT PLANNING; SAFETY; SIMULATION OF PHYSICAL SYSTEMS / PROCESS | 1 *each* |

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| **T. Astronomy** | | **3** |
| | ASTRONOMIC TELESCOPE DATA PROCESSING; GALACTIC SIMULATION; RADIOMETER SIMULATION | 1 *each* |
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| **U. Construction** | | **3** |
| | CONSTRUCTION MANAGEMENT; HIGHWAY MAINTENANCE AND RECONSTRUCTION; STRESS ANALYSIS OF MATERIALS | 1 *each* |
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| **V. Mobile Computing** | | **3** |
| | LOCATION-BASED SERVICE; MOBILE NETWORK PERFORMANCE; MOBILITY PREDICTION | 1 *each* |
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| **W. Retailing and Wholesaling** | | **3** |
| | CUSTOMER EXPERIENCE; INVENTORY CONTROL; STORE MANAGEMENT | 1 *each* |
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| **X. Space** | | **3** |
| | DESIGN OF SATELLITE CLUSTER SYSTEM; SATELLITE COMMUNICATION; SIMULATION OF PHYSICAL SYSTEM / PROCESS | 1 *each* |
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| **Y. Mining / Metals** | | **2** |
| | INVESTMENT DECISIONS; SURFACE MINE DESIGN | 1 *each* |
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| **Z. E-Business** | | **1** |
| | BUSINESS PROCESS REENGINEERING | 1 |
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| **AA. Economics** | | **1** |
| | FISCAL MODELING | 1 |
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| **AB. Public Administration** | | **1** |
| | INSTITUTIONAL REORGANISATION | 1 |
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| **AC. Sports** | | **1** |
| | AGENT BEHAVIOUR | 1 |
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| **TOTAL** | | **525** |

**Table 17: Agenda for Future Research**

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| **A. Agent-Based Simulation** |
| **EXPERIMENTATION:** Powerful tools are needed for setting up and executing ABS simulation experiments; Powerful tools are needed for generating statistical output; |
| **INTER-DISCIPLINARY:** Integration of multi-agent and game theory in the context of addressing the negotiation problem; Research on organizational adaption using information held by organizations (for e.g., in HR databases); Combining network-based epidemic simulations, spatial visualization, and geographic information in order to clarify spatial and temporal characteristics when analyzing pandemic preparation and control measures (Healthcare); |
| **MODELING AGENT BEHAVIOUR:** Modeling of crowd behaviour (including, obtaining observational data on pedestrian dynamics); Modeling adaptive cognition in agent-based models; Modeling the emergence of social norms; Incorporating decision model into existing military simulation systems to enhance their decision-making capability (Military/Defense); To model biological processes for which only knowledge exists about rough correlations, instead of well-established causal relations; |
| **TRAINING:** Developing simulations to support training soft skills such as leadership, cultural awareness, and negotiation tactics (Military/Defense); Interactive training simulations that allow multiple trainees to connect to the simulations in order to stimulate cooperation among them (Military/Defense); |
| **USABILITY OF ABS:** Improved documentation (including complete documentation of classes and methods, with examples); Continued development and maintenance of template models and "how-to?" documents; Integration of ABS software libraries with Integrated Development Environments (IDEs) like Eclipse; Improving the trade-off between ease of use and generality of ABS platforms; |
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| **B. Communication Networks** |
| **APPLICATION-SPECIFIC:** Comparing different multicast congestion control algorithms in a very large group environment (Multicast Applications); Development of models to mimic streaming applications (Streaming Applications); |
| **MODELS:** Development of scientific and engineering foundation for detailed models that characterize physical layer characteristics such as signal propagation, signal attenuation due to terrains/foliages, multi-path fading, shadowing, jamming and interference; Development of scientific and engineering foundation for power consumption models incurred in CPU, memory access, NIC processing, coding/ modulation and other associative circuitry (such as acoustic sound, seismic or temperature sensors and actuators); |
| **NETWORK-SPECIFIC:** Future research in tool for simulating the transmission of connection-oriented traffic over a constellation of LEO/MEO (low/medium earth orbit) satellites (Space-based Network); Issues related to mixing traffic at different levels of resolution with different load demands (Large-scale Networks); Development of sophisticated simulation models to better quantify the upstream (client) and the downstream (server) and server behaviour (Networks with High-speed Data Access); |
| **QOS:** Development of a broader class of scheduling algorithms for QoS support in WANs and to compare their performance against different types of traffic (Wide Area Network); |
| **ROUTING:** Thorough evaluation of the impact of network topology on the performance of routing algorithms; Adapting localized routing to vast networks such as the Internet through a combination of local information and aggregate global information; Future research on hybrid routing in ultra-large-scale networks and wireless sensor networks; Research towards scalable and lightweight routing protocols for very large-scale mobile ad hoc networks; Implementation of models for content-based routing, data diffusion, and information dissemination; |
| **SECURITY:** Simulation of diverse types of network intrusions ; Implementing of robust attack-detecting functions for Intrusion Detection Systems (IDS) ; Future research on developing web services for Network Traffic Analysis (NTA); Development of simulation models with vulnerability database for the fast construction of various model types according to attack types and security policies; Development of scientific and engineering foundation for models of various intrusion/attack scenarios (such as denial of service, man-in-the-middle attack, message tampering, eavesdropping and replaying); Development of scientific and engineering foundation for representative security mechanisms/policies in the literature (such as packet sniffers, IPV6, IPsec, firewalls and DNSSEC) and key distribution/authentication mechanisms; |
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| **C. Component-based Modeling and Simulation/ Interoperability/ Model Sharing and Reuse** |
| **DEVS:** Research in distributed reconfiguration and port-based structure transformation is needed to conduct safe and efficient dynamic change of component-based systems; |
| **INTEROPERABILITY:** Research in interoperability of Multi-Paradigm Modeling techniques to achieve the objective of enabling the modellers to use different modeling techniques in conjunction; Model interoperability in military simulations (Military/Defense); Interoperability between C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) systems and simulation (Military/Defence); Need for true "plug-and-play" interoperability of simulations and supporting software (Manufacturing); Research in workflow modeling & simulation and HLA will facilitate supporting the next-generation of information systems for interoperating networked enterprises (Enterprise Process Modeling); |
| **MODEL SHARING AND REUSE:** Research into global compositional consistency related to construction of models from reusable components; Development of a shared air transportation simulation repository of data, models and |

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| computational tools, together with processes (including administrative processes) by which institutions may access, contribute and benefit from this repository (grand challenge in aviation); |
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| **D. Computing and Simulation Experimentation** |
| **COMPUTATIONAL EFFICIENCY:** Research into methodologies pertaining to simulation experimentation that achieve a compromise between efficacy (or achieving the optimum decision among many competing alternatives) and efficiency (or time required to achieve it); Increasing the computational efficiency of genetic algorithms for modeling of ecological systems (Ecological Systems); |
| **EXECUTION TIME:** Research focussing on an order of magnitude reduction in problem-solving cycles is needed for pervasive use of modeling and simulation for decision support in current and future manufacturing systems (Manufacturing); Research in establish rules for the parallel implementation of first- and second-order quantized state systems methods in ordinary differential equations (ODE) and differential algebraic equation (DAE), and quantify the benefits obtained in terms of execution time reduction (ODE and DAE); Speeding-up architectural simulations for high-performance processors (grand challenge pertaining to microprocessors); Incorporation of techniques such as distributed simulation, parallel simulation, and hardware-in-the-loop components to keep simulation times reasonable (Network Simulation); |
| **SCALABILITY:** Enhancing the scalability of simulators without affecting the confidence in the simulation results (Network Simulation); |
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| **E. Distributed Systems** |
| **LOAD SHARING:** Further research in performance of epoch load sharing in heterogeneous distributed systems; |
| **MODEL EXECUTION:** Research focussing on the execution of complex models on heterogeneous architectures formed by shared memory, LAN- and Internet-connected machines, or in a Grid environment; A simulation framework that can support the design of applications that do not necessarily use MPI but are executed in HPC-like large-scale computer systems; |
| **SCHEDULING:** The need for further research in cluster scheduling tools that can encompass a diverse range of platforms and application characteristics; To examine the impact of the communication overhead on the performance of an open queuing network model of a distributed system in the context of parallel job scheduling in homogeneous distributed systems; Further research on scheduling algorithms used by a server to improve stability in the cluster environment; |
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| **F. Formal Specifications/ Rules/ Standards and Reference Models** |
| **FORMALIZATION OF DESIGN:** Formalizing the design of real time RTI (RT-RTI), for e.g., by comparing DEVS with other formal languages such as Timed Automata; |
| **FORMALIZATION OF SEMANTICS:** Investigation and formal treatment of transformation semantics that facilitate the development of scientific simulations; Formalization of the semantics of all interacting features that WS-CDL and WS-BPEL are capable to express through use of communicating sequential processes-based approach to verify web services in business process design (Business Process Design); |
| **REFERENCE MODELS:** Concrete suggestions for pragmatic standards and reference models (Military/Defence); |
| **RULE DEFINITION:** Establish rules for the parallel implementation of first- and second-order quantized state systems methods (QSS and QSS2) in ordinary differential equations (ODE) and differential algebraic equation (DAE) (ODE and DAE); Research is required to simplify rule definition for quantized models (related to building complex continuous systems using DEVS-based approaches); The implementation and analysis of simulation-based rules should be extended to more complex manufacturing systems, such as systems with assembled products and systems with distributed controls (Manufacturing); |
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| **G. Healthcare** |
| **MODEL DEVELOPMENT:** Incorporating visualization techniques into traditional simulation systems; Development of stochastic optimization algorithms for scheduling patients; Focussing on the individual level of care and incorporate patient care needs and their perspective into the simulation models; |
| **MODELING HUMAN BEHAVIOUR/EXPERT KNOWLEDGE:** Future work is needed to better capture human behavior in simulation models (related to both the execution of tasks and the scheduling of appointments); Simulation models need to capture human behavior by drawing on, for example, the fields of human–computer interaction (HCI) and computer-supported cooperative work (CSCW); Artificial Intelligence needs to be incorporated in order to model expert knowledge of hospital management; |
| **TELE-MEDICINE:** Future research in the shifting of telemedicine from desktop platforms to wireless and mobile configurations; |
| **WHOLE SYSTEM APPROACH:** Further study of hospital department as part of a larger system by combining different techniques such as discrete-event and systems dynamics techniques to provide multi-level views of the problem; The typical healthcare workflows are extremely complex, and therefore further research into schedule-aware workflow management systems is required so that the whole healthcare workflow is taken into account; |
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| **H. Model Building** |
| **CONCEPTUAL MODELING:** Research towards unfolding the conceptual models of the simulation systems as clearly as possible (Military/Defence); |
| **INPUT DATA ANALYSIS:** Research in neural networks in the field of probability distribution selection; |
| **MODELING ASSUMPTIONS:** Development of methodology for dealing with causal dependencies of model assumptions; Standardization of pragmatic and conceptual issues in model building, including handing of model assumptions; Investigation pertaining to how important hidden assumptions are in different domains and how to make them explicit; |
| **VERIFICATION AND VALIDATION:** With the size and complexity of simulation systems growing rapidly, further research into the design of simulation verification, validation and accreditation schemes (VV&A) has become a necessity; |
| |
| **I. Multi-Paradigm Modeling/ Meta-Modeling/ Symbiotic Simulation/ Hybrid Simulation** |
| **HYBRID SIMULATION:** Combining different techniques such as discrete-event and systems dynamics techniques to provide multi-level views of the problem; Use of poisson simulation (PoS) for enabling combined simulation consisting of sub-models of both continuous system simulation and discrete event simulation types; Exploration of multi-algorithm and/or multi-scale combinations including an Asynchronous Event-Driven (AED) component (e.g., the use of sophisticated neighbour search methods developed in the computational geometry community, such as using quad/oct-trees, in AED implementations); |
| **META-MODELING:** The design and comparison for alternative simulation meta-models; |
| **MULTI-LEVEL MODELING (INCLUDING SUB-MODELS):** Implementation of complex, multi-level models in ABS frameworks (Agent-Based Simulation); Development of sub-models (pertaining to, for example, disturbances, regeneration, and mortality processes that affect the simulated dynamics and the sensitivity of the model) as well as their integration in forest dynamics models for simulation of long-term dynamics (Environment); |
| **MULTI-PARADIGM MODELING:** Building a research roadmap for multi-paradigm modeling which addresses the necessity of using multiple modeling paradigms when designing complex systems; Integrative multi-modeling for the purpose of providing a human-computer interaction environment that allows components of different model types to be linked to one another; Computer automated multi-paradigm modeling (grand challenge in system design); |
| **SYMBIOTIC SIMULATION:** Experimenting with symbiotic simulation systems where real-time components can cooperate in various ways with simulation components; |
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| **J. Parallel and Distributed Simulation** |
| **MIDDLEWARE:** Implementation of a low-cost distributed simulation environment by using the Web-enabled RTI or an RTI based on a General Public Licence (GPL), which can be used instead of the higher-cost commercial RTI implementations; Extending the RTI+ middleware to provide interoperability support for different COTS simulation packages based on standards such as the entity transfer specification developed by the HLA-CSPIF group; |
| **OPTIMISTIC PROTOCOL:** Research towards incorporating load-balancing and fault tolerance mechanisms into the optimistic Time Warp kernel; Further investigation of throttling mechanisms that can be used to reduce the cost of the optimistic approach; More accurate modeling of real systems by exploring techniques to remove the termination bias in a look-ahead simulation; |
| **OR/MS:** Collection of end-user requirements to make distributed simulation technology to be easily used by OR/MS practitioners; Using distributed simulation to simulate large models created using COTS simulation packages; Extending the RTI+ middleware to provide interoperability support for different COTS simulation packages based on standards such as the entity transfer specification developed by the HLA-CSPIF group; Focus on addressing the potential impact of PADS in industry by engaging with industrial partners; Further work in the design of friendly user interfaces, which is a requirement for building COTS package-based distributed simulations; Research effort from wider simulation community to develop and improve distributed simulation technology for commercial software, with particular attention to the affordability and ease of implementation; |
| **PARALLEL SIMULATION:** Further research in parallel simulation of logical-process models; Further Investigation of dynamic memory management in parallel simulation; |
| **PESSIMISTIC PROTOCOL:** More accurate modeling of real systems by exploring techniques to remove the termination bias in a look-ahead simulation; |
| **TRAINING:** Utilizing HLA's Data Distribution Management to characterize various types of distributed mission training-style architectures (Military/Defence); |
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| **K. Others** |
| **ECOLOGICAL MODELING:** Further research pertaining to the addition of two emerging technologies - evolutionary computation and eco-informatics - to computational ecology for building better ecological models; |
| **EDUCATION:** Extending the concept of creating new modeling notations and solutions to mathematics; Visual language exploration in computer science classes as a means of comprehending the relevant topical material; |
| **ENTERPRISE PROCESS MODELING:** A Petri Net-based approach for automated context-aware web service composition; Future research in service orchestration; |
| **EQUATION-BASED MODELING:** Future research into a time-driven continuum diffusion partial differential equation solver that can be used to model processes at macroscopic length scales; Further research into Differential Inclusions |

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| (DIs) solvers (DIs represent an important extension of differential equation); |
| **FOOD INDUSTRY:** Studies that compare the outputs of the simulation experiments and the actual plant implementations (this would be a valuable step in further demonstrating the value of simulation in the food industry); |
| **GENERAL:** Profiling literature in OR/MS (including, bibliometric analysis, meta-data analysis, co-citation analysis); Aesthetic Computing (grand challenge); Exploration of the possibility of using chaotic iterative sequences in place of pseudo-random numbers in simulation-based schemes such as importance sampling and neuro-dynamic programming; Future research in reflective simulation for modeling the computerized production, ecology, and service systems; It would be valuable in future work to determine whether revised best-practices recommendations (software developers are traditionally admonished to maintain the simplest code required to attain the desired output, under the presumption of improved reliability, maintainability, and reduced processing load), given a target processor, could be made to simulation software developers, as opposed to lengthy and costly testing on a case-by-case basis; |
| **GPU:** Further research in GPU technology, as GPU could become the processor of choice for many applications; |
| **HIGH-LEVEL LANGUAGE:** Modeling and simulating continuous behaviour of models with Maude; Future research into the next generation of Very High Speed Integrated Circuits (VHSIC) Hardware Description Language (VHDL) which is built on the modeling and simulation principles of GDEVS; Developing appropriate architecture description languages (ADLs) for the simulation community; A compiler architecture to support discrete events; |
| **MANUFACTURING:** Further research in pervasive use of modeling and simulation for decision support in current and future manufacturing systems through the development of real-time, simulation-based problem-solving capability; |
| **MINING:** Development of robust and comprehensive Computational Intelligent Algorithms to improve the optimization of surface mine layouts; |
| **ROAD TRANSPORTATION**: Using neural network, genetic algorithms, and fuzzy logic–based controllers to design adaptive traffic control systems; |
| **SUPPLY CHAIN:** Integration of supply chain management function and sales & marketing function in simulation models; Investigating processes for generating graphical output data such that decision makers can see how the supply chain acts over time during simulations; |
| **SYSTEMS BIOLOGY:** Research into new tools and better modeling processes to facilitate further progress in pathway modeling in systems biology; Development of generic, but domain-aware, multi-scale partitioning algorithms for efficient execution of sytems biology models; |

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